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ELECTRICAL MINING INSTALLATIONS

By

P. W. FREUDEMACHER

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PREFACE

THIS volume has been written especially for colliery engineers and contractors engaged in the installation of electrical plant for mining purposes.

The first chapter deals briefly with the elementary principles of electrical engineering, special reference being made to alternate current working. Many readers will already have a sufficient knowledge of these principles and for them the volume will be a guide to the application of electric power for mining work.

Readers who are engineers but not essentially electrical engineers will find this opening chapter of service, and it is hoped that the notes on alternate current working will clear up the many abstruse points on this subject and give a working knowledge of the terms and quantities involved.

The author has described various classes of plant for all mining purposes and has given formula and tables so that the necessary calculations in regard to power, outputs, etc. may be made. It is impossible to avoid mathematics altogether in a practical book for engineers; but examples have been carefully prepared in order to show how the more elaborate calculations are to be accomplished.

The last chapter on electric winding systems has

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been included to complete the subject opened up in the previous chapter, and although the installation of a main winding engine is perhaps a matter for experts in this particular branch, the volume would not have been complete without reference to this matter.

P. W. F.

CONTENTS

CHAPTER I PAGE
GENERAL PRINCIPLES 1

CHAPTER II
GENERATING PLANT 11

CHAPTER III
GENERATING STATION SWITCHGEAR 23

CHAPTER IV
TRANSMISSION 39

CHAPTER V
UNDERGROUND CABLES AND FITTINGS . . . 62

CHAPTER VI
ELECTRIC HAULAGE. 87

CHAPTER VII
ELECTRIC PUMPING 107

CHAPTER VIII
ELECTRIC COAL CUTTING AND DRILLING . . . 123

CHAPTER IX
ELECTRIC VENTILATING 129

CHAPTER X
ELECTRIC WINDING 134

CHAPTER XI
ELECTRIC WINDING SYSTEMS 146

CHAPTER XII

PAGE
SPECIAL RULES FOR THE INSTALLATION AND USE OF ELECTRICITY 163
Definitions 163
Section I. General 164
„ II. Generating Stations and Machine Rooms . 168
„ III. Cables 169
„ IV. Switches, Fuses and Cut-outs . . 172
„ V. Motors 172
„ VI. Electric Locomotives 174
„ VII. Electric Lighting 175
„ VIII. Shot-Firing 176
„ IX. Signalling 177
„ X. Electric Relighting of Safety Lamps . 177
„ XI. Exemptions and Miscellaneous . . 178
INDEX 179

LIST OF ILLUSTRATIONS

FIG.		PAGE
1.	Alternating Pressure and Current Curves	5
2.	Curves showing Three-Phase and Two-Phase Systems	6
3.	Curve showing Pressure and Lagging Current with Resultant Power Curve	9
4.	Diagram of Connexions for Compound Wound Interpole Generator	16
5.	Connexions for Three-Phase Windings	17
6.	Diagram of Connexions for Continuous Current Switchboards	26
7.	Diagram of Connexions for Three-Phase Switchboard	28
8.	Section through Three-Phase Switchboard	31
9.	Continuous-Current Leakage Indicator	35
10.	Diagram for Three-Phase Leakage Indicators	37
11.	Poles for Transmission Lines	46
12.	Terminal Pole	48
13.	Shaft Cable Suspenders	67
14.	Method of Running Cables in Roads	69
15.	Flexible Cable-Suspender	71
16.	Shaft Cable Junction Box	72
17.	Road Cable Junction Boxes	73

FIG. PAGE
18. Road Cable Junction Boxes 74
19. Callender's Gate-end Box 78
20. Fisher's Patent Gate-end Box and Plug . . 80
21. Plug: Fisher Patent System 82
22. Plan of Main Haulage Gear 87
23. Main and Tail Haulage Gear 89
24. Reversing Controller for Continuous Current Motors 93
25. Three-Phase Reversing Controller . . . 94
26. Section through Turbine Pump . . . 109
27. Characteristic Curve of Turbine Pump . . 112
28. Auto Transformer Starter Diagram . . . 113
29. Star Mesh Starter 114
30. Winding Engine Load Curve 135
31. Types of Winding Drums 143
32. Siemens-Ilgner Winding System . . . 149
33. Winding Engine Load Curve 151
34. Crompton Winding System 153
35. Westinghouse Winding System 157
36. Westinghouse Winding Engine and Control Gear . 160

LIST OF TABLES

No.		PAGE
—	Particulars of Conductors	52
—	Particulars of Conductors	54
I.	H.P. Required for Main and Tail Haulage at 10 Miles per Hour	98
II.	H.P. Required for Endless Rope Haulage on Road 1,000 Yards Long	99
—	Approximate Friction in Feet Head per Yard of Pipe	118

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CHAPTER I

GENERAL PRINCIPLES

The use of electric power for mining work represents one of the greatest developments in the electrical industry during recent years. It is of course understood that electricity is utilized only as a means of transmitting power, which has to be generated in the first place, e.g. by burning coal and raising steam, which is turned into mechanical power by the steam engine, then converted into electrical power by means of the dynamo or electric generator, and back again into mechanical power for use at the various places where it is wanted.

The power might, of course, be transmitted by means of compressed air, by hydraulic means, or in certain cases, by running steam pipes from a boiler to the spot where power is required and there installing a steam engine. Compared with the transmission of energy by this means, it must be admitted that electricity is more convenient and efficient.

At first sight it would not, perhaps, appear to have any great advantage from an economic standpoint, but the gradual development of the industry has shown that electrical equipments must play a very important part in all up-to-date colliery installations.

With electric driving the generating plant can be installed in one central station (instead of being scattered as was generally the case before the advent of electric driving) and from the main switchboard power circuits can be run to places where energy is required for winding, hauling, pumping, ventilating, coal-cutting, lighting and other work.

Electricity lends itself admirably to ease in distribution, over wide and scattered areas, with the utmost economy, and at the same time, additions and extensions can be readily carried out. Taking everything into consideration it is obvious that this method of power transmission has great advantages for colliery purposes.

In a few cases power may be provided by a supply authority, in bulk, but, more generally, each colliery will have its own central power station to generate the electrical energy required. In most cases this latter course is justified, for fuel is cheap, and power can thus be generated at a low cost.

Before dealing with the matter of generating plant we will consider for a moment the question of choice of systems. Electrical energy for lighting and power purposes may be supplied as continuous or as alternating current, the latter being sub-divided into single- two- and three-phase current. The choice of the system to be adopted depends upon many circumstances, and can only be settled after full consideration.

The continuous current system may be very suitable for small installations, where the distances are not great, nor the conditions severe, and, in all probability, for a small installation, continuous current will prove cheapest in the long run.

For large installations, however, alternating-current working is almost a necessity, and in many cases, where the power station is situated at some distance from the shaft, or the workings extend to a considerable distance underground, it is necessary to work on the high-tension alternating-current system. It is customary to adopt a three-phase, high-tension system in such cases; two-phase is very seldom used, and single-phase is never considered for power work of this nature.

It will be as well to set out clearly the principles of the various systems and their relative advantages.

Taking the continuous current system first, it is presumed that Ohm's law is familiar to all—

$$\frac{E}{R} = C, \text{ or } \frac{E}{C} = R, \text{ or } E = C.R.$$

When E = Electro-Motive force or E.M.F. in volts.
,, R = Resistance in ohms.
,, C = Current in amperes.

From the third expression, $E = CR$, we can obtain the pressure lost in any conductor due to resistance.

If, for example, we know that 110 yds. of 19/16 cable has a resistance of ·044 ohm, then, with a current of 60 amperes flowing, there will be a loss of $60 \times \cdot044 = 2\cdot64$ volts.

It is, of course, understood that the resistance of the total length of cable must be taken, i.e. lead and return.

Power in a continuous current system is represented by the product of volts and amperes, $E \times C$ = Watts; but in dealing with large values it is more usual to talk of Kilowatts (K.W.), that is 1,000 watts. Since $E \times C$ = Watts or W. it follows that the energy lost in transmitting electricity through a conductor is given by the expression: Lost Volts × Amps., but since Lost Volts = Resistance × Amps., the energy lost may be represented by the formula $C \times C \times R$ or C^2R.

From these calculations it will be seen that, in order to limit the lost volts, or "pressure drop" as it is more often called, and also to limit the energy or watt loss, it is necessary to provide a conductor of ample size, especially when electricity has to be transmitted over great distances. The alternative is to increase the voltage, and, by so doing, not only is the pressure drop reduced in proportion (because for a given power the amperes are reduced proportionately) but this pressure drop bears a still smaller ratio to the increased voltage.

As a matter of fact, the percentage pressure drop is improved in proportion to the square of the voltage, so that, by doubling the voltage, our percentage pressure drop becomes only one-fourth, assuming the same amount of power to be transmitted through a given conductor.

Now on glancing for a moment at our formula for energy loss—C^2R—it will be noted that, under the same conditions, our lost watts will only be one-fourth with twice the pressure. It will thus be seen that it is advisable to adopt as high a pressure as practicable, consistent with safety and ease of working.

Before going further it will be advisable to define the limits of pressure as fixed by the Home Office in connexion with the use of electricity in mines:

(*A*) Low-pressure supply—where the conditions of supply are such that the pressure at the terminals where the electricity is used, cannot exceed 250 volts.

(*B*) Medium pressure—where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250, but cannot exceed 650 volts.

(*C*) High-pressure supply—where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 650 but cannot exceed 3,000 volts.

(*D*) Extra high-pressure supply—where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts.

We will now take the case of an alternating current system, and, as three-phase is used almost exclusively, we will confine ourselves practically to a consideration of this system, although the remarks may be taken as generally applicable to single-phase and two-phase systems of supply.

As is well-known, single-phase alternating pressure, or current, may be represented by a sine curve (Fig. 1, *A*) from which it will be noticed that the current, or pressure, starting from zero, increases to a maximum, decreases to zero again, then reverses, increases to a maximum in the other direction, and again decreases to zero, this being termed a cycle or period, usually referred to as the frequency or periodicity, and expressed in so many cycles per second.

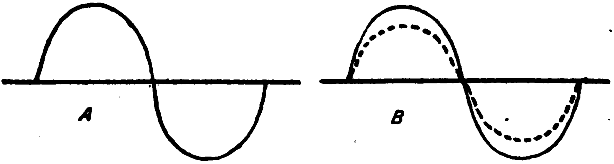

FIG. 1. ALTERNATING PRESSURE AND CURRENT CURVES.

The frequency is usually of the order of 25–60 cycles per second, although, in special cases, it may be as low as 15 for railway work, or as high as 100 for lighting purposes in scattered districts.

These special cases, however, do not concern us at present, and it may be taken that 50 cycles has practically been adopted as standard for lighting and power work, and 25 cycles as standard for extensive power supply only.

The illustration, Fig. 1, *B*, shows the pressure or voltage curve for a single-phase supply in full, and the current curve in dotted lines; further, the two curves are shown "in phase," that is to say the voltage and current curves both pass through the zero point, and both reach their maximum at the same time; but it by no means follows that this is so in all cases, as we shall see.

The three-phase system may be described as three single-phase systems, so arranged as to differ in phase as shown in Fig. 2 (*A*), while the two-phase system is equivalent to two single-phase systems arranged to differ in phase as shown in Fig. 2 (*B*).

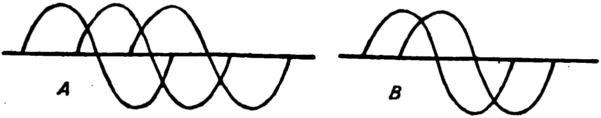

FIG. 2. CURVES SHOWING THREE-PHASE AND TWO-PHASE SYSTEMS.

We will not enter into further detail here, in regard to these alternating current systems, which are again dealt with in the chapters on generating plant and transmission respectively.

When speaking of continuous current we assume that the pressure is the constant or maintained voltage between two conductors, or between one conductor and earth; but in alternating current work we have no such constant voltage, as the latter is always varying between zero and a maximum, and also constantly changing its direction or sign; we have therefore no positive or negative conductor, since each conductor in turn is alternately positive and negative.

What then are we to understand by voltage in connexion with an alternating current supply? If the terminals of such a supply are connected to an electrostatic, or a hot wire voltmeter, previously calibrated for continuous current, we shall find that the instrument settles down to a reading which is an average of the pressure wave. Speaking more correctly, we may say that the value is the square root of the mean square of the vertical ordinates representing pressure. This, however, need not

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trouble the reader, because we shall always, in future, refer to the voltage of an alternating current supply in terms of "virtual" volts, that is, the average, or root-mean-square volts, such as would be recorded on an electrostatic, hot wire or other properly calibrated instrument.

The same remarks hold good in reference to amperes in an alternating current circuit, and we shall henceforth refer to "virtual" amperes such as would be recorded on a hot wire or other type of properly calibrated ammeter.

It is, of course, obvious that we cannot measure alternating pressure or current on continuous current instruments of the moving-coil type, which are only suitable for current passing in a certain direction. Space cannot be spared to enable us to enter into this matter in greater detail, and readers desiring a more extensive knowledge of alternating currents in theory, will be able to obtain same from one or other of the special treatises on this subject.

Here, we are only concerned with the practical application of electricity to mining purposes: but it will be as well, for the sake of those having little practical experience of alternating currents if we clear the ground somewhat as regards the application of Ohm's law to alternating current work.

We have seen that, in dealing with continuous currents, the relation between pressure, current, and resistance, is given by Ohm's law. This law also holds good for alternating currents, but is rather complicated by a factor known as "reactance." This reactanee is similar in effect to resistance, except that it does not necessarily involve a waste of energy, which always occurs when current passes through a resistance.

In alternating current practice we have to take into account the combined effect of resistance and reactance, and the combination is technically known as impedance, the value of which is obtained by taking the square root of the square of the resistance, plus the square of the reactance, thus

$$\sqrt{\text{Res.}^2 + \text{React.}^2} = \text{impedance.}$$

With this modification, Ohm's law then becomes—

$$\frac{\text{E}}{\sqrt{\text{Res.}^2 + \text{React.}^2}} = \text{C},$$

$$\frac{\text{E}}{\text{C}} = \sqrt{\text{Res}^2 + \text{React.}^2}$$

$$\text{E} = \text{C}\sqrt{\text{Res.}^2 + \text{React.}^2}$$

It is impossible to deal further, here, with the nature of reactance, but sufficient has been said to make the expression clear, and the matter will be referred to again as occasion demands. Suffice it that in calculating the pressure drop in cables or transmission wires, the reactance will not, in ordinary cases, affect the result to any practical extent.

Before leaving this part of the subject, a word must be said regarding power in alternating current circuits. We already know that power in a continuous current system is represented by the product of volts and amperes; but this is not necessarily true in regard to alternating current work.

Referring to the curves shown in Fig. 1 (*B*) it will be noted that the current and pressure are "in phase," that is to say they each pass through the zero line at the same instant, and the power may be obtained by multiplying the volts and amperes at any instant, and plotting another curve. If then an average be taken of this power curve, we shall obtain the true power, which is exactly the same as the product of the virtual volts and virtual amperes.

The pressure and current curves will always be in phase as long as the external circuit includes resistance only; but, if reactance is present, the current curve will lag behind the pressure curve in point of time, and will be as shown in Fig. 3. In actual practice the pressure and current are never absolutely in phase, and in the majority of cases, where motors are running on the circuit, the current may lag very considerably behind the pressure.

It is possible, under certain circumstances, that the current may lead in phase, but as this very seldom occurs in practice we need not deal with the matter here.

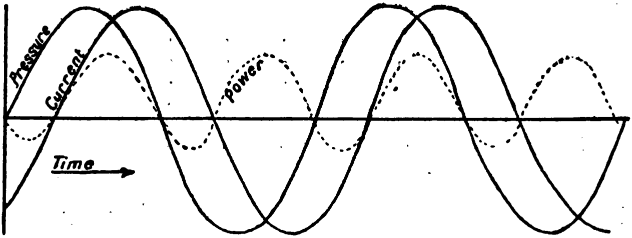

FIG. 3. CURVE SHOWING PRESSURE AND LAGGING CURRENT WITH RESULTANT POWER CURVE.

Referring again to Fig. 3, if we multiply the volts and amperes at any particular instant and plot a power curve we find that at times there exists a positive voltage and a negative current, or a positive current and a negative voltage, which means that at such times we have negative power, and the power curve will be as shown. If we take the average of this curve, and subtract the negative from the positive part, we shall find that the result is considerably less than the product of the virtual volts and amperes.

We now have two expressions :—

(*a*) The apparent watts obtained by multiplying the volts and amperes.

(*b*) The true watts obtained from the curve.

From these two expressions we obtain a new ratio, technically known as "power factor."

$$\text{Power factor} = \frac{\text{TRUE WATTS.}}{\text{APPARENT WATTS.}}$$

This quantity is sometimes referred to as Cos. ϕ.

because it is also arrived at by calculating the cosine of the angle of lag, generally known by the Greek letter ϕ.

It is obvious, from the above, that the power factor must always be less than unity, and, as a matter of fact, the following average values may be assumed in actual practice :—

Incandescent Lighting	·95
Mixed Lighting	·85
Synchronous machinery	·95
Well loaded large induction motors .	·85 to ·90
Average loaded induction motors . .	·70 to ·80
Ditto ditto with lighting . . .	·75 to ·85

Power factor is also sometimes referred to as a percentage, thus 85 per cent. power factor = ·85.

It is evident from the foregoing that power in an alternating current system can be calculated from the expression :—

Volts × Amperes × Power factor = Watts.

This refers particularly to single-phase; and the corresponding expressions for two-phase and three-phase working are as follows :—

Two-phase :—Volts × Amperes × Power factor × 2 = Watts.

Three-phase :—Volts × Amperes × Power factor $\times \sqrt{3}$ = Watts.

This matter is further dealt with in the chapter entitled "Transmission," to which the reader is referred for further particulars.

CHAPTER II

GENERATING PLANT

The source from which electrical energy has to be obtained is the first important consideration. In many cases it so happens that electricity is supplied in a district by one of the modern electric power companies, which have sprung up in recent years. These concerns can often supply electricity in bulk, at such a price that it would not pay the colliery owner to generate on his own account and, if suitable terms can be arranged, it may be good policy to take such supply in bulk instead of erecting a private generating station.

Before deciding, many considerations will have to be taken into account, and the actual cost of electrical energy may not be the predominating factor. One great advantage should be the saving in capital expenditure, and the interest and sinking fund charges thereon, as well as maintenance and supervision costs.

In many parts of the country at present, no such bulk supply is available, and local colliery owners have no option but to purchase plant, and erect their own generating station. It must be admitted that, in the majority of moderate and large installations, this course is entirely warranted, because plant may be put down of a type best suited to the requirements of the case, and the generating costs (taking everything into consideration) thus reduced to a figure which will compare favourably with that charged by bulk supply authorities.

Having decided that the colliery is to be equipped with its own electric generating station, we are confronted with an almost endless variety of systems and types of plant, suitable for the purpose.

Fuel may be burnt under boilers, and steam generated, for conversion into mechanical power by steam engines or steam turbines; or, where the coal is of the coking variety, we can employ gas engines and utilize the coke oven gas.

Large gas engines have not hitherto found favour in this country, although used extensively on the Continent, but there is now every indication that the adoption of such plants for colliery purposes is being seriously considered, and several plants have already been put down.

It is a remarkable fact that, whereas, years ago, colliery plants were worked on most uneconomical lines (so far as fuel consumption is concerned), at present great attention is given to this branch of the subject, and all the latest and most modern improvements adopted to reduce fuel consumption to a minimum.

The older installations were worked at a low steam pressure, with a long range of steam pipes, together with inefficient engines and auxiliaries, but we now find the most up-to-date boilers, working at high pressure, with economizers, superheaters, scientifically-designed steam range, triple-expansion engines with low steam consumption, condensing plants, and electrically-driven auxiliaries; all of which tend to reduce the fuel costs, per unit generated, to the lowest possible value.

This is especially necessary when the coal is of good quality, and for which a high price can be obtained in the market. On the other hand, some coal brought to the surface may be of very low grade, and here again we find that boiler furnaces have been so improved, that, in conjunction with forced draught, this class of fuel may be utilized for raising steam, instead of being consigned to the waste heap because it has no market value.

Further, we notice that colliery installations now include the most modern and up-to-date appliances in boilerhouse plant, e.g., mechanical stokers, coal and ash conveyors, and similar labour-saving devices, all designed to reduce operating costs.

We need not enter into further detail in regard to the design of boilerhouse plant, as the question does not lie directly within the scope of this volume ; and the next matter to engage our attention is the engine, or prime mover.

In regard to steam engines, present day tendency in colliery power stations is to emulate the example of the public supply authority, and adopt high-speed, vertical, enclosed engines, or, in some cases, steam turbines. It has been proved that this class of engine is entirely suited to the somewhat trying conditions of colliery service whilst their efficiency is high ; at the same time the small floor area occupied by these high-speed sets is a great advantage where space is limited.

Colliery men in the past, however, could not get away from the class of engine to which they had been accustomed, viz., the slow speed, horizontal type, as used for winding, etc., and some of the earlier installations still include electric generators driven by ropes or belts from such slow-speed horizontal engines. There is no doubt, however, that in nearly all modern colliery power stations, the high-speed, enclosed, vertical engine has found its place, and proved eminently suitable for the work.

Coming now to electric generating plant, one of two systems is generally employed, namely the continuous-current, or the three-phase alternating current system.

The various power companies supplying electrical

Google

energy in bulk in this country, have all adopted the high-tension, alternating-current system, and this is practically the only one under which power can be efficiently transmitted over great distances. If, then, it be decided to purchase electrical energy in bulk from such a source, the conditions of supply are fixed, although the pressure may be transformed down, to any suitable value, for distribution to motors, etc. Such a supply can also be converted into continuous current by means of rotary converters or motor-generators if necessary.

In the event of a colliery company deciding to put down their own generating station, it is open for them to adopt continuous or alternating current supply, and this brings us to the question of the relative advantages of the two systems for mining work.

This question has practically resolved itself in favour of the three-phase alternating-current system, although, as before stated, continuous current may suffice for small installations where the distances to be covered are comparatively small, and the conditions not severe.

It is, perhaps, not surprising that the three-phase alternating-current system should have found such favour, because, in addition to the efficient distribution of energy over great distances, and the ease with which the pressure may be transformed from high into low tension as required, three-phase motors themselves possess several advantages over continuous-current machines. For instance, three-phase motors of the short-circuited rotor type, represent the simplest possible construction, having no commutator or rubbing contacts whatever, nor complicated starting gear. In fact, for small machines, no starting gear is required, other than the usual three-pole switch, and such a machine will start, and run up to speed, with a current equal to about three times the normal. Then again, the cost is much less than that of a corresponding continuous-current motor with its attendant starting gear.

Three-phase motors, with wound rotors and slip rings, have advantages over continuous-current machines, in the absence of commutator and sparking troubles, and the constant attention necessary to keep a continuous-current machine in working order. Three-phase machines are better mechanically, and there is less likelihood of breakdown; consequently the cost of repairs and maintenance is much smaller.

One important point must not be overlooked, viz., the fire risk, which is a minimum with three-phase motors, owing to the absence of a commutator.

Apart from motors, the three-phase alternating-current system has great advantages from the power distribution standpoint. For instance, a three-core, three-phase, armoured cable, down the shaft or in the roads, makes a much better job than two continuous-current conductors, while the cost of such a cable, for a given pressure, is usually less.

On the other hand, it must be admitted that, for a certain class of duty, continuous current has the advantage, particularly in regard to traction by locomotives, in connexion with which continuous-current motors are practically indispensable, but as there has been little demand in this country for such service this argument carries little weight.

For a long time there seems to have been a deep-rooted objection to the use of three-phase motors for coal cutters, and at one period it was considered necessary to employ continuous-current machines for this work, but, with improvements in three-phase motors for this purpose, coal cutters are being adopted on alternating-current systems with complete success.

It is unnecessary to enlarge upon continuous-current generating plant, except perhaps to add that machines should be compound wound, to secure an increase in pressure between no load and full load. Continuous-current generators for mining work should also be capable of withstanding considerable overloads without sparking or damage. Most firms manufacturing this class of plant now provide machines with interpoles, which automatically compensate for armature reaction, and enable the sets to withstand very considerable overloads without sparking or need for altering the position of the brushes; in many cases the position of the brushes is permanently fixed and no facilities are provided for adjustment after the machine has left the makers' works.

The diagram, Fig. 4, shows internal connexions

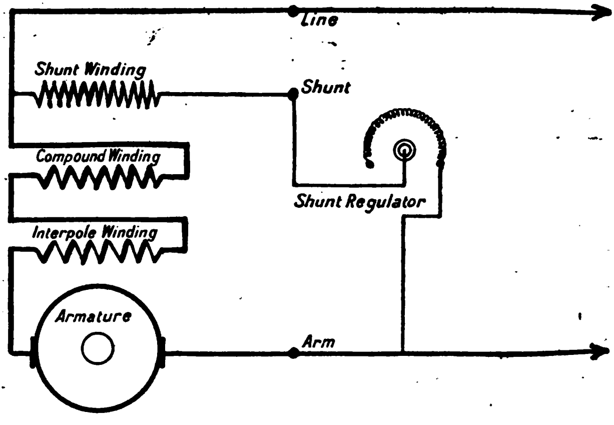

FIG. 4. DIAGRAM OF CONNEXIONS FOR COMPOUND WOUND INTERPOLE GENERATOR.

of a multipolar, compound wound, generator with interpoles.

With regard to A.C. machines, these are usually of the stationary armature type, with revolving fields, the necessary excitation being provided from some external source, as an alternator cannot be self-exciting like a continuous-current machine.

The exciter consists of a continuous-current generator of comparatively low voltage, often direct coupled to the alternator shaft, and driven by the same engine, but continuous current from any suitable external source can be employed for magnetizing

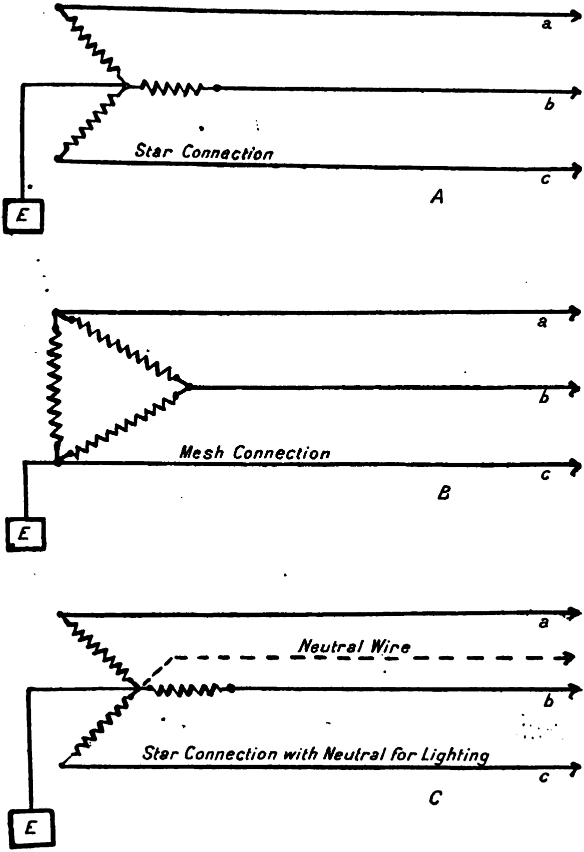

Fig. 5. Connexions for Three-Phase Windings.

the revolving field of the alternating current machine.

As already explained, the armature windings of two-phase or three-phase machines really consist of two or three separate single-phase windings so placed as to give a different phase relation between the individual circuits as shown in Fig. 2. There are, however, two distinct methods of coupling up the windings for a three-phase supply, known technically, as "star" and "mesh" (or delta, as the latter is sometimes called, because the arrangement takes the form of a triangle, the Greek letter "Δ"). Fig. 5 will make this clear.

In referring to the voltage of a three-phase system, we always understand the pressure between lines, i.e. between *a* and *b*, *a* and *c*, or *b* and *c*, which are, or should be, equal.

It will be obvious from the diagram that if each of the three single-phase windings gives a certain voltage, X, the pressure between the outgoing lines will depend upon the arrangement of connexions adopted. If X represent the voltage, and Y, the current, of each single-phase winding, then the resultant voltage and current of the three-phase system will be as follows:—

(*a*) Star connexion: Volts between lines $= X \times \sqrt{3}$
Current in each line $= Y$.

(*b*) Mesh connexion: Volts between lines $= X$.
Current in each line $= Y \times \sqrt{3}$

Thus the result, so far as power is concerned, is the same in each case, but each method has its advantages or disadvantages, more particularly as regards external conditions.

Three-phase motors may be connected, "star" or "mesh," in the same way as alternators, and all such motors are provided with three terminals, to which corresponding lines of the three-phase system are connected.

In mining practice it is customary to earth some point of the system, and with the "star" connected alternator this is usually the centre or neutral point; in "mesh" connected machines it is usual to dispense with earth connexions but one or other of the junctions of the phases may be temporarily earthed for testing purposes as shown in the diagram.

If the alternating-current generators are also required to provide the power necessary for lighting it is usual to adopt the "star" system of connexion and also to run out an additional conductor from a neutral point as shown in Fig. 5 *C*, in which case the lighting load is connected between the neutral wire and each line, care being taken to divide it uniformly between the three phases. With this arrangement of connexions the lighting pressure is only equal to that between the lines, divided by $\sqrt{3}$ (1·73 approximately) so that, to assume a case, the pressure for motors may be 400 volts between the lines, and that for lighting, 230 volts between neutral and each line wire.

It is not, of course, absolutely necessary to balance the lighting on each phase, exactly, although this should be done as far as possible. In the event of unequal balancing the out-of-balance current returns through the neutral wire.

In alternating-current generators we have another factor to deal with, namely "frequency," or "periodicity," recorded in cycles per second. As explained previously, this frequency is usually 50 cycles per second for lighting, or for mixed lighting and general power work, and 25 cycles per second for large power systems only. The frequency for any particular machine is given by the formula :—Number of pairs of poles × R.P.M. ÷ 60.

From this it will be seen that as the number of pairs of poles must be some whole number (without a fraction) we are limited to certain definite speeds in order to obtain standard frequencies. For instance, a 50 cycle generator for direct coupling to a high-speed engine must run at 300, 333, 375, 428, 500, etc., revolutions per minute, and no intermediate speeds are possible. For the same reason, in a 25 cycle generator the speeds are even more restricted, and we have to choose between 300, 375, 500, etc., revolutions per minute.

There is one other point in regard to the output or capacity of alternating-current generators, which is perhaps not thoroughly understood and appreciated by all engineers. This is the power factor referred to in a previous chapter.

We have already seen, that, provided there is no lag or phase difference between the pressure and current curves, the power in any three-phase alternating-current circuit is given by the expression: Volts $\times$ Amperes $\times \sqrt{3} =$ Watts, but when conditions are present which cause a lag or phase difference, the power is less than it otherwise would have been, as shown by the expression:

Volts $\times$ Amperes $\times \sqrt{3} \times$ Power factor $=$ Watts.

In any three-phase alternating-current generator, the voltage and current are fixed, and these, together with the speed, determine the size of the machine, but the actual output in true watts or kilowatts will depend upon external conditions, which must be known before the capacity of such a machine can be specified.

In a previous chapter a table of probable power factor values has been given for different classes of work.

This question of power factor has another effect on the performance of the machine. All electric generators are subject to a decrease in pressure as the load increases, unless this is compensated for by a compound winding, or by interpoles, as on continuous-current machines. No such satisfactory method has been found to yield similar results on alternating-current machines, and we therefore have to face the fact that the latter, working under conditions of constant speed and excitation, have an inherent tendency towards loss in pressure as the load comes on.

With machines supplying a lighting or non-inductive load, where there is no appreciable lag between pressure and current, and where the power factor is consequently equal to unity, this decrease in pressure, or "pressure drop," will be in the neighbourhood of 5 per cent. to 7 per cent., but the same machine supplying an inductive load, with a power factor of say, ·8, will have a corresponding pressure drop of the order of 14 per cent. to 20 per cent. The exact value will depend entirely upon the characteristic of the machine in question.

In giving these figures for pressure drop it is of course assumed that the speed and excitation remain constant, for it is obvious that the pressure may be varied by altering the excitation, and, in practice, the excitation would be altered by means of the field regulating resistance, to compensate for the fall in pressure. By this means the pressure can be maintained constant, provided that some one is in attendance, to adjust the field regulating resistance to suit the requirements of the load.

Various automatic devices have been brought out from time to time, for automatically varying the excitation to keep the pressure constant under all conditions.

The power required to drive any electric generator when the output in kilowatts is known, is given by the formula :—

$$\text{B.H.P.} = \frac{\text{Watts}}{746} \div \text{Efficiency.}$$

When the efficiency is expressed as percentage, we divide it by 100. For instance, if we require to know the power necessary to drive a 100 k.w. (that is 100 × 1000 watts) generator having an efficiency of 89·5 per cent. at full load, we obtain :—

$$\frac{100{,}000 \text{ Watts}}{746} \div \frac{89{\cdot}5}{100} = 150 \text{ B.H.P.}$$

From this it will be seen that the horse-power required, is equal to about 1½ times the kilowatt capacity of the machine, and this approximate rule will often prove useful, but it must be remembered that the horse-power will be greater, in the case of small machines of low efficiency, and less with large machines having a higher efficiency.

In connexion with alternating-current generators, we often come across the expression K.V.A. or kilovolt-amperes, i.e., the product of volts and amperes, divided by 1,000, or in other words the apparent kilowatts. From what has already been said it follows that, by multiplying together the apparent kilowatts and the power factor, we obtain the true kilowatts, and it must be mentioned that, when calculating the horse-power required to drive a generator, we must always take the true and not the apparent kilowatts or k.v.a. output.

Machines are often referred to in terms of their k.v.a. capacity, and this fixes the size of the machine, but at the same time conveys no idea of the true output in kilowatts in any particular case, or the power required to drive, unless we know the power factor of the circuit which the machine has to supply; obviously the machine will require maximum power to drive it when the power factor is highest, viz., 1·0, in which case the kilowatt output is equal to the k.v.a.

CHAPTER III

GENERATING STATION SWITCHGEAR

MUCH might be written on the subject of generating station switchgear for mining installations, but we must confine ourselves to general principles and give details only so far as they lie within the scope of this manual.

In the first place special conditions have to be complied with in the Home Office rules, the salient features being embodied in the following abstract.

"There shall be a passage-way in front of the switchboard of not less than 3 ft. in width, and if there are any connexions at the back of the switchboard, any passage-way behind the switchboard shall not be less than 3 ft. clear. This space shall not be utilized as a store-room, or a lumber-room, or obstructed in any manner by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passage-way must be widened accordingly. No cable shall cross the passage-way at the back of the board except below the floor, or at a height of not less than 7 ft. above the floor.

"The space at the switchboards shall be properly floored, accessible from each end, and, except in the case of low pressure switchboards, must be kept locked, but the lock must allow of the door being opened from the inside without use of a key. The floor at the back shall be incombustible, firm, and even.

"Every generator shall be provided with a switch on each pole, between the generator and the busbars.

"Where continuous-current generators are paralleled reverse current cutouts shall be provided.

"Suitable instruments shall be provided for measuring the current and pressure of each generator.

"Every feeder circuit shall at its origin be provided with an ammeter.

"If the transmission lines from the generating station to the pit are overhead there shall be lightning arresters in connexion with the feeder circuits.

"Automatic cutouts must be so arranged that, when the contact lever opens outwards, no danger exists of striking the head of the attendant. If unenclosed fuses are used they must be placed within 2 ft. of the floor, or be otherwise suitably protected.

"Where the supply is at a pressure exceeding the limits of medium pressure, there shall be no live metal work on the front of the main switchboard within 8 ft. of the floor or platform, and the space provided under Rule 2 of this section shall be not less than 4 ft. in the clear. Insulating floors or mats shall be provided for medium pressure boards where live metal work is on the front or back.

"All terminals and live metal on machines over medium pressure above ground, and over low pressure under ground, shall, where practicable, be protected with insulating covers, or with metal covers connected to earth.

"The insulation of every complete circuit, other than telephone or signal wires, used for the supply of energy, including all machinery, apparatus, and devices forming part of, or in connexion with such circuit, shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current and suitable means shall be provided for the immediate localization of leakage.

"In every completely insulated circuit, earth or fault detectors shall be kept connected up, in every generating and transforming station, to show, immediately, any defect in the insulation of the system. The readings of these instruments shall be recorded daily in a book kept at the generating or transforming station, or switch-house.

"Main and distribution switch and fuse boards must be of incombustible insulating material, such as marble or slate, free from metallic veins, and be fixed in as dry a situation as practicable.

"Every sub-circuit must be protected by a fuse on each pole. Every circuit carrying more than 5 amperes up to 125 volts or 3 amperes at any pressure above 125 volts must be protected in one of the following alternative methods:—

(*a*) By an automatic maximum cutout on each pole.

(*b*) By a detachable fuse on each pole, constructed in such manner that it can be removed from a live circuit with the minimum risk of shock.

(*c*) By a switch and fuse on each pole."

Dealing, first with continuous-current boards it will be seen that the pressure would in practically all cases lie between 250 and 650 volts, such installations coming under the heading of medium pressure supply.

Fig. 6 is a typical diagram of connexions of a continuous-current generating station switchboard, with two or more compound-wound generators and several feeder circuits. Such boards are usually constructed of plain or enamelled slate, in a wrought-iron frame, with the switching apparatus and instruments mounted on the front of the panels, the back of the board being utilized for busbars, connexions, instrument shunts, regulating resistances, etc. Owing to the simple nature of the general lay-out, and construction, an illustration showing the details of continuous-current boards is unnecessary, the general features of such being familiar to all.

The apparatus on the panels of a typical switchboard controlling shunt-wound generators may be detailed as follows :—

Each Generator Panel contains—

One amperemeter, preferably dead-beat, moving-coil pattern.

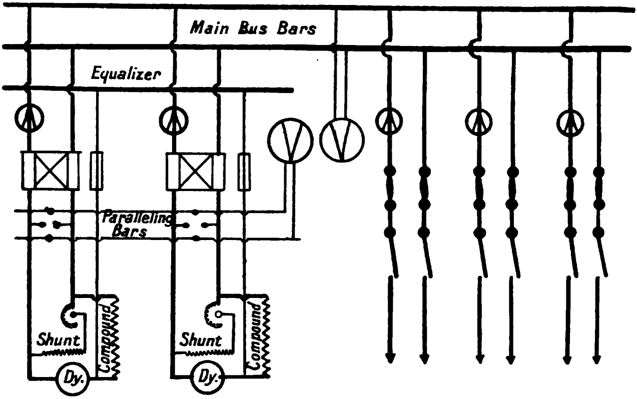

FIG. 6. DIAGRAM OF CONNEXIONS FOR CONTINUOUS CURRENT SWITCHBOARDS.

One single-pole, overload and reverse current automatic circuit breaker on positive pole.

One single-pole switch on negative pole.

One single-pole fuse on negative pole.

One shunt field regulating rheostat.

One field-breaking switch and non-inductive resistance.

One set of paralleling sockets and plug.

Common to all generator panels there should be a main busbar voltmeter (usually mounted over the centre of the complete board); also one paralleling voltmeter which can be connected to the paralleling sockets, so that the voltage of the incoming machine may be adjusted before switching it into parallel with the running machines. Sometimes this paralleling voltmeter is mounted on a swinging bracket, at one end of the board, so as to be distinctly visible to the switchboard attendant.

Each Feeder Panel contains—

One amperemeter, preferably of the dead-beat, moving-coil type.
One double-pole switch.
Two single-pole fuses.

This is, perhaps, the simplest possible form of board, and there is practically no end to the elaboration and refinements that could be added if desired. For instance, double-pole circuit breakers are sometimes placed on the generator panels as shown in Fig. 6 with or without switches, but, as most double-pole circuit breakers can also be used as main switches, especially if they are of the loose handle type, and cannot be held on in the event of a persistent fault, there is no advantage gained by using switches in addition.

With compound wound machines equalizing switches will be necessary, and these usually take the form of a single-pole switch, placed on the board, in which case an equalizing busbar will have to be provided; or the equalizing switches may be placed on the machines themselves. It will be at once apparent from the diagram that there is a great saving of cable in adopting this latter method, and, as the equalizing cable is of substantial section there will be a considerable saving in cost.

Coming now to three-phase alternating current switchgear, we have boards for medium pressure, where the voltage lies between 250 and 650 volts; and also boards for high-pressure, where the voltage exceeds the latter figure but does not exceed 3,000 volts.

The following remarks will also apply generally to extra high pressure switchgear, but such schemes are rarely necessary for mining installations and we need not specially consider them.

Fig. 7 is a typical diagram of connexions for a three-phase generating station switchboard, and will apply generally to both medium and high-pressure installations. The apparatus on the various panels may be detailed as follows :—

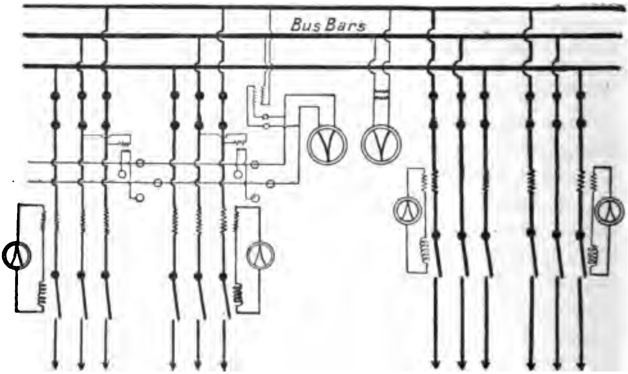

FIG. 7. DIAGRAM OF CONNEXIONS FOR THREE-PHASE SWITCHBOARD.

Each Generator Panel contains—

One triple-pole oil break switch, fitted with alternating current instantaneous overload trip coils in two phases.
Two current transformers for operating trip coils.
One amperemeter (probably operated from one of the above transformers).
One main field regulating rheostat for alternator.
The necessary synchronizing plugs and sockets.

Each Exciter Panel contains—

One double-pole switch.
Two single-pole fuses.

One exciter amperemeter.
One shunt regulating rheostat.

Each Feeder Panel contains—

One triple-pole, oil break switch, fitted with alternating-current instantaneous overload trip coils in two phases.
Two current transformers for operating trip coils.
One amperemeter (probably operated from one of the above transformers).

A main busbar voltmeter will also be necessary, and may be placed over the centre of the board.

In addition, a paralleling or synchronizing voltmeter will be required, this being connected to the synchronizing busbars as shown.

For important boards a synchronizer might also be fitted, such an instrument showing at a glance whether the incoming machine is running too fast or too slow. This apparatus is not, however, absolutely necessary, and is often omitted. In any case it is usual to have synchronizing lamps, so that the engine driver, and switchboard attendant, can tell when the incoming machine is in phase with those already running.

The triple-pole oil break switch should preferably have a free handle attachment, so that it is impossible for any one to hold this on while a persistent fault exists. The switches referred to above have two trip coils, but obviously one, two, or three trip coils can be fitted as required. The general rule is to use two; this arrangement gives protection against overload in all three phases, because the current in the unprotected phase cannot build up without also increasing the current in the other two. When generators are supplying a lighting system, with a neutral conductor, or when the neutral is permanently earthed, it is preferable to fit three trip coils on the main generating-station feeder switches.

Alternating-current, instantaneous trip coils, are in series with the circuit they are required to protect, and may be direct connected in the case of a medium pressure board, but it is more usual to employ series transformers. Such transformers are absolutely necessary in the case of high pressure boards, in order to eliminate all high pressure parts from the front of the panels, and they are often employed for medium pressure boards, partly because it enables better arrangement of the main current busbars and connexions behind the panels.

The same remarks apply to the amperemeters, which may be operated from one of the trip coil transformers if desired, although, for various reasons, it is sometimes preferable to instal independent transformers for the purpose.

Voltmeters will, in the case of medium pressure boards, be connected across the main busbars, but for high pressure boards potential transformers will be necessary; all instruments on the face of the board operating on low-tension current.

A main field-regulating resistance has been mentioned for the alternator, and a shunt regulating resistance for the exciter fields, but here, again, one or other regulator may be employed alone, unless it is required to utilize the exciter circuit for other purposes such as lighting, in which case both will be necessary.

Since the general construction of the three-phase board is quite special, and very different from that of a continuous-current board, it will be as well to illustrate the arrangement, and Fig. 8 represents a section through a typical generator panel; it must however be understood that arrangements differ very widely, according to local requirements, and the space available.

The panels for three-phase boards are usually of polished white marble, mounted in an iron frame, and it will be seen from the illustration that considerable depth is necessary to accommodate the apparatus. The illustration applies more particularly to a high-pressure board of which the panels contain low-tension apparatus only, series and pressure transformers being employed in all cases, and placed in fire-proof compartments, so that, in the event of any accident arising, the switchboard attendant may be quite safe, and the damage confined to one particular compartment.

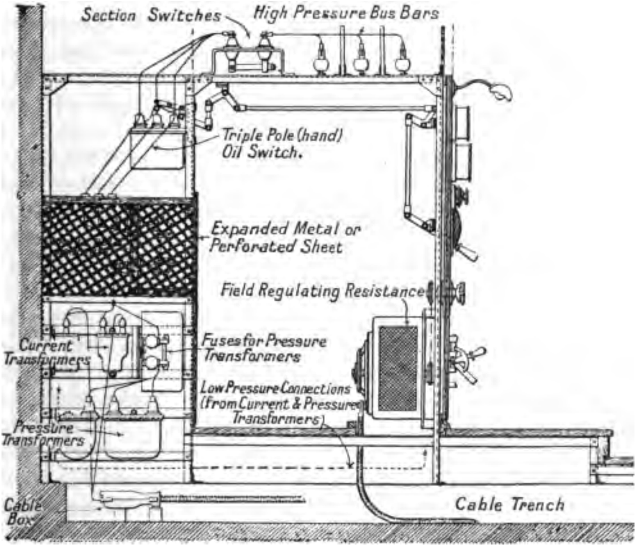
Section Switches
High Pressure Bus Bars
Triple Pole (hand) Oil Switch.
Expanded Metal or Perforated Sheet
Field Regulating Resistance
Current Transformers
Fuses for Pressure Transformers
Low Pressure Connections (From Current & Pressure Transformers)
Pressure Transformers
Cable Box
Cable Trench

FIG. 8. SECTION THROUGH THREE-PHASE SWITCHBOARD.

It will be noticed that a passage way is provided between the board, and the compartments at the back, containing the high-tension apparatus; access to this passage way being obtained through doors at one or both ends, and, according to regulation, the doors must be fitted with locks which can only be opened with a key from the outside, but are negotiable from the inside, without a key.

On high-tension boards it is also necessary to fit isolating or section switches. These usually take the form of copper links, and are not required to break a current, which should always be first dealt with on the oil switch; they are merely to isolate any particular portion of the board, so that alterations, repairs, cleaning, or inspection, may be carried out without risk or shock. In some cases isolating switches are so interlocked with the doors leading to the chambers or compartments that access to these compartments cannot be obtained until the isolating switch has been opened, and conversely, that the isolating switches cannot be replaced until the compartment is again closed.

Nothing has been said about fuses for three-phase alternating current boards, and, as a matter of fact, it is not usual to fit them on generating station panels, except, perhaps, on lighting and small feeder circuits, while for high pressure boards, fuses of any kind are rigidly avoided.

It can easily be shown that a fuse does not give the required protection for three-phase work, while at the same time, the cost of fuses is equivalent to that of automatic trip coils fitted to the main oil switches. In the first place a fuse cannot be depended upon to operate with absolute certainty at any predetermined current value, and, further, it can only operate to the accompaniment of more or less noise, smoke, and flashing, often damaging surrounding fittings, and causing a disturbance generally. Further, it cannot be replaced as quickly as an automatic oil switch, and it is necessary to stock replacements to suit every type and capacity of fuse fitted.

In addition to these disabilities, a fuse may only blow on one or two poles, and maintain the pressure on part of the system when it should be disconnected, whereas an automatic oil switch, fitted with one, two, or three trip coils, opens all phases instantly when the current reaches a predetermined value, and what is more important, current is always interrupted by an oil switch as it passes through zero, thereby minimizing the possibility of dangerous pressure rises, and lessening the resultant strain upon machinery, cables, etc.

Automatic trip coils on the oil switch are capable of adjustment, so that the switch can be temporarily under or overset if required, without interfering with the supply.

The above remarks apply generally to the employment of fuses on all three-phase boards, but in the case of high-tension service it is very difficult to design a satisfactory high-tension fuse that will fulfil the requirements, and operate with safety.

So far we have only considered the use of plain alternating-current instantaneous-overload trip coils for oil switches, but it may, in certain cases, be advisable to operate the trip coil through a relay of the time limit overload or reverse-current pattern. Time-limit overload relays may be designed to open very quickly on heavy overloads, but maintain a supply in the case of moderate overloads, the time varying inversely as the magnitude of the overload on the system. Reverse current relays are designed to trip the oil switch in the event of a current, or more correctly speaking, power reversal.

The Home Office rules insist on reverse current cutouts being provided where continuous-current generators are paralleled, but such cutouts or relays, working in conjunction with trip coils on the automatic switches, are often provided in connexion with three-phase generators running in parallel, the relays being used singly, or in conjunction with instantaneous or time-limit overload relays.

It is unnecessary to enter into a detailed description of these relays, suffice it that they are usually operated from series pressure transformers, and provided with relay contacts, so that it is only necessary to fit the oil switches with one trip coil in the relay circuit, this being energized by any of the relays and actuating the switch in the event of an overload or reverse current.

Time limit relays are often fitted to the outgoing feeder circuits, and a switchboard so arranged is in accordance with the best modern practice.

On three-phase alternating-current switchboards we sometimes find power factor indicators, idle current amperemeters, and frequency meters, but these instruments are not absolutely necessary for the general run of mining installations, and they represent refinements which can be safely omitted.

In regard to both continuous-current and alternating-current switchboards, integrating watt-hour-meters will probably be considered necessary to measure the output. In an important installation such wattmeters may be placed on each generator or feeder panel, but in other cases, wattmeters in the main busbars, between generator and feeder panels, which thus record the total output of the station, will be all that is necessary.

As there is a great deal of misunderstanding about types of wattmeters, it should be noted that an integrating watt-hour-meter is an instrument similar to a house service meter, which measures the total energy passed through it. An indicating wattmeter would merely indicate the watts passing at any given moment, while a recording wattmeter, like a recording voltmeter or amperemeter, gives a continuous record in the form of an ink line on a paper chart, showing the actual value of the watts in the circuit over a period. Obviously by integrating this curve we obtain watt hours, such as would be measured by an integrating watt-hour-meter.

Other recording instruments may also be employed in special cases, such as recording amperemeters and voltmeters, the latter being especially useful as a check on the station superintendent, since it shows how the pressure has been maintained, and how far it has been allowed to deviate from normal.

The Home Office rules in connexion with all mining electrical installations insist that the leakage current shall be kept within specified limits and due provision must be made for measuring the actual leakage current, which must not, under any circumstances, exceed one-thousandth of the maximum supply current; further means must be provided for immediately localizing any undue leakage.

Several types of leakage indicators have been designed to fulfil the required conditions, and the following particulars regarding one or two of the best-known types will show the general principles involved.

A leakage indicator by Messrs. Nalder Bros. & Thompson, for use in connexion with continuous-current circuits, having both mains insulated, is shown in Fig. 9. With this device a high resistance, of not less than 200,000 ohms, is connected across the mains, and the instrument, of moving coil type, is connected between the mid point of this resistance, through the switch, to earth, as shown in the diagram. With the switch in its normal position the instrument acts as an indicator of the condition of the mains;

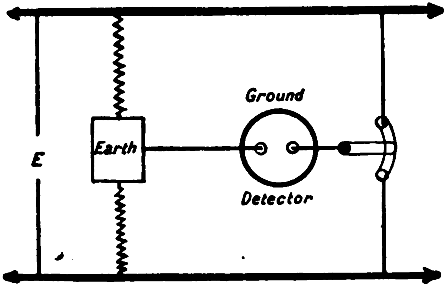

FIG. 9. CONTINUOUS-CURRENT LEAKAGE INDICATOR.

if the pointer rests in the centre of the scale it indicates equality in the insulation resistance of the mains; a deflection to right, or left, indicates faulty insulation of the negative or positive main respectively.

A 2-way switch is also supplied, and, in order to determine the exact value of the insulation resistance, this is turned to the right, and then to the left, the deflection being noted in each case; from these observations the insulation resistance of both mains, and also the leakage-current to earth may be calculated, but in order to eliminate the necessity for these calculations, a table of values is supplied with the instrument, from which the insulation resistance of both mains, and the current to earth in milliamperes, can be read off at a glance. The switch can only be left in the centre position, and, consequently, there is no likelihood of the main being left connected to earth through a relatively low resistance.

It is quite easy to provide this leakage indicator with an alarm arrangement, so that when the earth current exceeds the limit allowed by the Home Office rules, a bell is caused to ring in the station, thereby calling attention to the fact.

For alternating current work the same makers have designed a leakage indicator suitable for use where the neutral point is earthed and also on a mesh-connected three-phase system.

The principle made use of in this instrument is that of super-imposing a small continuous current on the alternating system. This continuous current is measured by means of a permanent magnet moving coil instrument, which is unaffected by alternating currents.

A source of direct current may be either a primary or secondary battery, small generator, or the exciter of the alternating current generator, but, generally speaking, a dry battery of about 50 volts is recommended. The moving coil instrument is so calibrated with the low-voltage battery, or other source of continuous current, as to indicate directly, in ohms, the insulation resistance between the system and earth.

In addition to the scales of ohms, the dial of the instrument has also a scale of amperes marked on it. The actual leakage current is never greater than the number of amperes shown by the instrument, although, under certain conditions, it may be less.

In the event of the insulation resistance of the system falling below Home Office requirements, a fuse is blown and closes a local bell circuit, thus calling attention to the fault.

The diagram, Fig. 10 (*a*), shows the general arrange-

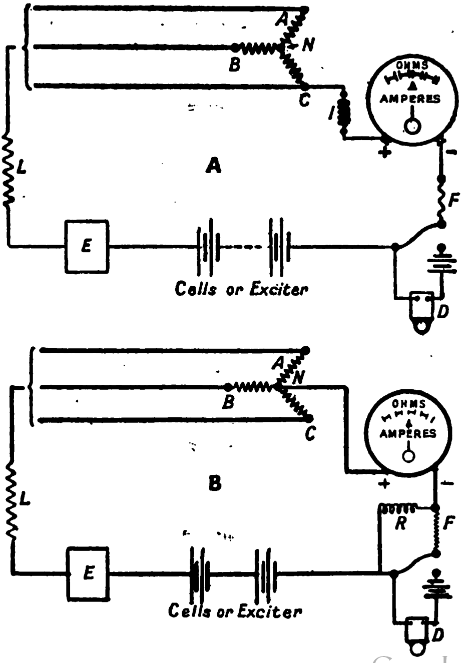

FIG. 10. DIAGRAM FOR THREE-PHASE LEAKAGE INDICATORS

ment for completely insulated three-phase circuits from which it will be noted that a large inductive resistance *I* is inserted in series with the ammeter; this prevents the flow of any appreciable alternating current to earth through the instrument. This resistance *I* takes the form of a choking coil, enclosed in an iron case, and provided with specially insulated terminals, so as to be suitable for connecting to a high tension circuit if necessary.

Fig 10 (*b*) shows the arrangement for circuits with earthed neutrals, and it will be noticed that the instrument is inserted between the neutral connexion and earth, the resistance of instrument, fuse, and battery being only about 5 ohms, or if the exciter is employed only about 1 ohm; consequently, the earthing of the neutral is in no way impaired. To prevent the neutral wire being entirely disconnected from earth when the fuse blows, a resistance *R* is connected in parallel with it, just large enough to prevent the current through the instrument, due to a leak, doing any damage.

The advantage of the above apparatus lies in the fact that the earth current is never greater than the reading shown on the instrument, and, further, capacity currents do not affect the indicators in any way.

When a fault has been indicated by the alarm bell, localization may be carried out with an ordinary insulation testing set.

CHAPTER IV

TRANSMISSION

THE whole question of the transmission of electrical energy is most important, in fact, the cost of transmission is often the determining factor, in deciding upon the best system for any particular installation.

It is assumed that the general principles governing the selection of any particular system, are more or less understood, but the limitations may be briefly stated as follows :—

Continuous current, at 220 volts, for lighting in compact districts.

Continuous current at 400 to 500 volts for mixed lighting and power work in a more extended district, the lighting being arranged on the three-wire system.

Continuous current at 400 to 600 volts for motors only, in an extended district, assuming that the distances are not excessive.

Three-phase supply, at 400 to 600 volts would be adopted under the same conditions as the last named, but there may, of course, be other circumstances in favour of three-phase supply. This matter is gone into more fully in Chapter I.

Three-phase supply, at 2,200 to 3,300 volts, would be used where the energy had to be transmitted a considerable distance, say 2 to 8 miles.

Three-phase supply, at 5,000 volts, and upwards, would be used for long distance transmission.

Any lighting that may be required on the three-phase system is easily provided for by installing a transformer to give the required pressure.

In the case of three-phase supply, a periodicity of 50 cycles will probably be chosen for a mixed lighting and power load, but for long distance transmission, with power load only, a periodicity of 25 cycles will have some advantages.

For short distance transmission insulated cables laid underground will probably be used; but where it is practicable to adopt overhead conductors, the cost will be considerably lower, especially for long distances. The method of calculating the size of conductor required, will be much the same, whichever system is used.

The size of the conductors will depend upon :—

(*a*) The current to be transmitted.

(*b*) The permissible voltage drop.

(*c*) The permissible current density.

The current to be transmitted, is, of course, determined by the power required, the particular system to be adopted, and the voltage.

The permissible voltage drop depends upon circumstances, but its usual value is of the order of 2½ per cent. for lighting, and 5 per cent. for power, except for long distances, when the drop may be 10 per cent., or even 15 per cent. for very long lines, of, say, 20 miles or more. The voltage drop is a function of the current transmitted, the size of conductor, and the distance.

The permissible current density is usually calculated on the basis of 1,000 amperes per square inch; under the more scientific reckoning of the Institution of Electrical Engineers the values vary for different size cables, as shown in the accompanying table. This current density only applies to insulated conductors and no such limitations are imposed on bare overhead wires, of which the size usually depends upon the permissible voltage drop.

Strictly speaking, there is another factor to be considered. So far we have only taken the technical points into account, but it is evident that commercial considerations are equally important. For instance, although we may save money by employing a conductor of small size, the energy loss will be relatively great, and this costs money to produce, so that we may be saving on prime cost and losing on working costs.

In 1881 Kelvin investigated with a view to discovering under what conditions both the value of the line and that of the energy lost in transmission were respectively a minimum. The result is embodied in the following formula, known as "Kelvin's Law."

"The cost, per annum, of the line losses, must be equal to the annual interest, and the depreciation of the line."

We can here only briefly state the law, but it has been found, by experience, that it is only in connexion with large and important schemes that it is necessary to apply it in practice.

To take a general example of the procedure in determining the size of conductor for continuous current transmission, assuming the power to be transmitted, the voltage, and the distance, to be known. The maximum current is first obtained, by dividing the power in watts, required at the far end of the line, by the voltage at that end. In the case of an insulated conductor this will usually suffice, by reason of the current density, but, after selecting the required size of cable from the makers' list, it will be as well to again check the size by multiplying the total resistance (lead and return) by the current, to ensure that the pressure drop is not excessive. If the pressure drop is too great, a larger cable must be employed. It will not, however, be possible to adopt a smaller cable if the pressure drop is found to be small, for the minimum size has already been fixed by the permissible current density.

In the case of an overhead bare conductor, the usual plan is to first settle the permissible pressure drop, then, dividing this by the current, we obtain the total resistance of the conductor required. With this information the size can now be easily chosen from the table. This conductor can in all probability be employed provided that the current density is not excessive, in which case there will be danger of the wire overheating. Current densities up to 3,000 amperes per square inch may be used for bare, and about 2,000 amperes per square inch for braided, aerial wires, and these values will be found to cover nearly all cases in practice.

There is one other point to remember in connexion with overhead wires, viz., that a No. 8 S.W.G. is the smallest permissible single conductor from a mechanical standpoint.

For a three-phase transmission system we proceed in a similar manner. If the conductor be insulated, and its size consequently fixed by the current density, we first obtain the current per phase by dividing the apparent watts by the voltage, and the quotient by $\sqrt{3}$; allow 1,000 amperes per square inch, or, in the case of large cables, calculate the area on the basis established by the Institution of Electrical Engineers.

It will be noted that the size of conductor is based on the apparent watts and not on the true watts; i.e., due allowance must be made for the power factor when determining the sizes of cables. The reason will be apparent on referring to the general principles of three-phase working, in the first chapter.

It will be necessary to check the size thus obtained, to see that the drop in pressure is not excessive. This is done by taking the resistance of the particular conductor or cable from the annexed table, or from the makers' list, and multiplying by the current per phase. The resistance must be that of a single line, and the fall in pressure, given by the formula, will then be the volts lost along that line. In order to find the drop in volts between lines (this being the usual way of measuring three-phase alternating pressure) the result must be multiplied by $\sqrt{3}$.

In the case of an overhead three-phase transmission line, with bare conductors, where the size is mostly settled by the permissible pressure drop, we proceed in the same way as for continuous current, not forgetting the factor $\sqrt{3}$. For convenience in calculation the Author has prepared the following formula, which will give the correct size of conductor, in a three-phase transmission scheme at once when the distance, current, and permissible voltage drop are known,

$$\frac{L \times C}{LV \times 24} = \text{Sectional area of each conductor in square inches.}$$

Where L = distance in thousands of yards.

Where C = current per phase.

Where LV = the permissible lost volts or pressure drop.

It is, of course, probable that there will not be a standard size of cable to fit in exactly with the result, and the nearest standard size must be adopted. It would be advisable to again check the result, if the cable differs much from the value required, and this is best done by taking the actual resistance from the list or table, multiplying by the current per phase, and by $\sqrt{3}$ when the result should not differ much from the pressure drop allowed for in the first formula.

As a large number of British collieries are now using bare overhead mains supported on poles it will not be out of place to give a few general particulars of this system, before proceeding to a consideration of insulated cables for surface and underground use.

In the first place, the wires or conductors should be of hard-drawn high conductivity copper. This is necessary on account of mechanical strength. Aluminium conductors are employed in a few instances, but this metal has several disadvantages compared with copper, although, when the market price of copper is high, alluminium will show some advantage in first cost.

It is common practice to use bare copper wires, but, in some instances, conductors covered with a single, double, or triple layer of braid, served with a special weather-resisting compound, are used. Such a conductor may consist of a single wire or be made up into a strand of seven, nineteen, thirty-seven wires, etc., acording to the capacity required. It must be understood that the braiding, and serving of compound, are not relied upon for insulating purposes, but merely as a protection against chemical fumes or the weather.

Bare conductors are more usually solid, and not stranded. The size of any one conductor may be anything from No. 8 S.W.G. up to No. 000 S.W.G., the latter being as large as is convenient to handle. If a still larger capacity be required, two or more single conductors of the requisite size may be run in parallel on the same poles.

If the capacity required be considerable, say 200 amperes or more, a stranded cable of the necessary area may be used. It is obviously impossible to support such a cable on poles the usual distance apart, and in such cases, the cable may be made up of soft copper strand, for convenience in handling, and slung, at frequent intervals, from a steel suspension wire, by suitable suspenders, the suspension wire being carried on insulators in the usual way. The stranded wire, in such case, is usually braided, and treated with weather-resisting compound.

Poles for supporting overhead transmission lines are usually of wood, although steel poles are sometimes used. The former are mostly of redwood, well creosoted, in order to resist the weather. On a straight run they would be spaced about 130 feet apart, i.e., about 40 to the mile, but on curves, and through rough country, it may be necessary to place them closer together.

They are generally from 20 to 40 feet in length, the diameter (usually measured 5 feet from the butt, or large end) being anything from 6 to 12 inches according to length of pole, and the strength required. For light, single lines, single poles may be used, but for heavy lines, it may be advisable to adopt A, or H poles, in order to secure the necessary strength with a minimum of timber. Fig. 11 shows the single, A, and H poles respectively, together with the usual arrangement of cross arms. The illustration also shows bracing and stay wires. They depict poles by Messrs. Wade, and, in a recent paper before the Institution of Electrical Engineers, Mr. C. Wade gave the results of experiments, carried out to determine the relative strengths of various sizes and forms of pole.

Space will not permit full particulars here, but it may be stated, briefly, that the A pole appears to be most satisfactory for heavy lines, where a single pole cannot be used, and is about four and a half times as strong as a single pole of equal area, in a direction of right angles to the wires, and about twice as strong in the direction of the wires. The spread of the pole should be about $\frac{1}{8}$ of the height.

The H pole is chiefly used as a terminal pole at the end of a transmission line. For this position the double H pole is often used as suitable for taking the heaviest strains.

The cross arms may be of oak, or, if preferred, of galvanized iron. In a continuous-current system, an insulator will probably be fixed at each end of the cross arm, and, if more than one pair of conductors has to be carried, a separate cross arm will be provided for each pair.

For three-phase transmission it is usual to dispose the wires in the form of a triangle, one insulator being fixed at each end of the cross arm and the other at the top of the pole. If two three-phase lines have to be carried they may be arranged on three cross arms, one complete three-phase circuit on either side of the pole,

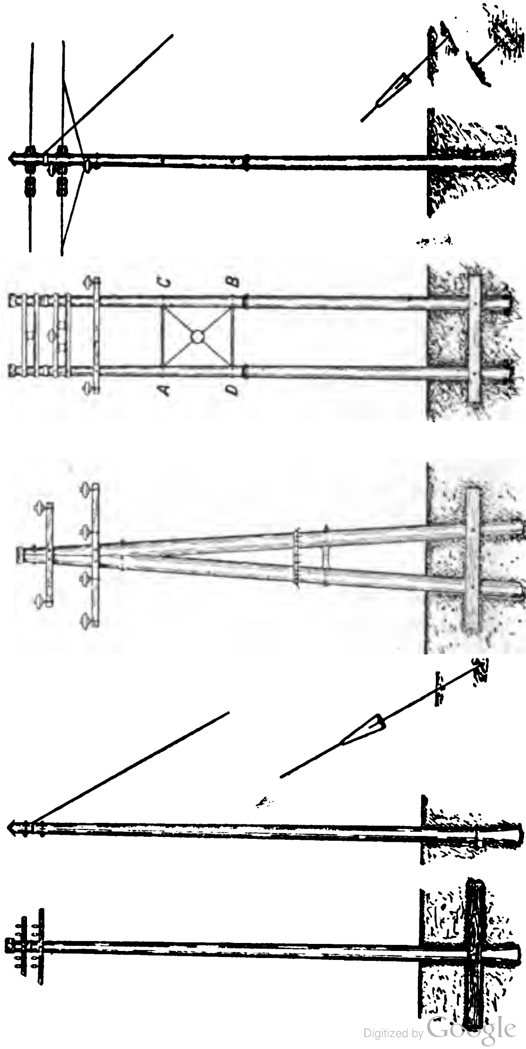

FIG. 11. POLES FOR TRANSMISSION LINES.

the conductors being one above the other, or, alternatively, as shown on the A pole in Fig. 11.

Lightning arresters are installed at both ends of the line and also at every point where power may be taken from it en route. Such lightning arresters may conveniently be placed in the station, or substation, together with the necessary choking coils. These latter are necessary to ensure that, in the event of the line being struck, the discharge shall not reach the generators and motors, otherwise the insulation would most certainly suffer.

On long lines it is also customary to place lightning arresters at equi-distant points along the route, usually every half-mile ; these, however, are merely earthed, and choking coils are unnecessary. In some cases a galvanized iron wire is run up each pole to form a lightning conductor. This wire projects some few inches beyond the top of the pole, while at the base an earth is obtained by coiling a length of the wire in the form of a spiral and burying it in the ground. It is possible that this form of lightning protector may be efficacious, and it has the advantage of being cheap, but is no good unless the earth connexion is properly made. In all cases where a reliable earth connexion is necessary, copper earth plates should be used. These should be about 4 feet square, and should have a substantial lug riveted or brazed on, for connecting purposes.

Such an earth plate is then buried deep below ground, in a bed of coke. Provided the ground is moist, this will make an efficient and reliable earth connexion, but in some positions owing to the nature of the ground it may be found necessary to keep the earth moist artificially by means of a special water supply.

One of the chief points in connexion with an overhead transmission line is the design of the terminal poles and leading-in arrangements. Where the transmission line leaves the power station, or substation, the connexions from the switchboard will probably take the form of a three-core armoured cable, which may be laid underground, to the base of the terminal pole, then cleated up the pole, and led into a special form of branching box, from which the separate leads,

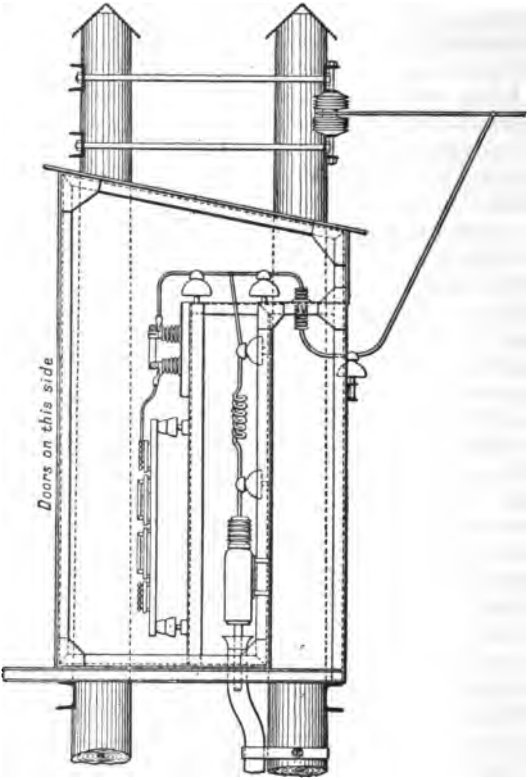

FIG. 12. TERMINAL POLE.

to the three transmission wires, (assuming a three phase supply) would be taken.

With such an arrangement the lightning arresters will have to be placed in the station. If, however, it is desired to fix the lightning arresters on the terminal pole, the arrangement will be as shown in Fig. 12. Several alternative designs are possible, but the one shown is typical. It will be seen that the incoming or outgoing transmission line is terminated on some form of shackle insulator, provision being made to take the strain off the last span. The connexion is then formed, by another bare copper conductor, from the lightning arrester to the insulated cable leaving the pole. The particular type of arrester shown, is that known as the "Wurtz," and consists of a number of serrated metal cylinders, mounted close to one another, but preserving a sufficient distance to prevent the line pressure from jumping the gap. The high tension lightning discharge easily crosses the intervening space, and passes to earth by way of the earth plate, the main current being prevented from following or setting up an arc, by virtue of the special non-arcing metal, of which the cylinders are composed. In addition to the metal cylinders, there are resistances in series and in parallel, to secure the proper working of the apparatus.

Above the lightning arrester will be noted the isolating switch, which renders the apparatus "dead" for purposes of inspection and adjustment.

The connexion to the three-core cable is made through a few turns of bare copper conductor, which form a choking coil, and prevent the high tension, high frequency, lightning discharge, from passing along the cable. The connexion from the choking coil is led into the cable box and properly sealed. This box encloses the connexion between the bare conductor and the insulated cable leading down the pole away to the power station or substation as the case may be.

The cable in this particular case, is run inside a steel pipe, cleated to the pole as shown. With such an arrangement of terminal pole, it is, of course, absolutely necessary to provide a complete housing round the lightning arresters, isolating switches, and choking coils, to protect them from the weather.

If the overhead transmission line is from the power station to a pit shaft, the connexion at the latter end should be taken to a switch panel, on which are mounted the lightning arresters, isolating switches and choking coils. This panel may be placed in an adjacent building, or set up in a suitable cast-iron pillar, erected at the foot of the terminal pole. It will be noted that the switches shown only isolate the lightning arresters, and, if it is required to disconnect the transmission line from the outgoing, or incoming, cables, another set of isolating switches must be provided for the purpose.

The special rules covering the installation and use of electricity in mines, require that an efficiently enclosed, locked switch box, or switch house, shall be provided near the pit mouth, for cutting off the supply of electricity to the mine, if the generating station is not within 400 yards of the pit mouth. In practice it will be found convenient to provide this switch in all cases where an overhead transmission line is used, especially as it is such a simple and inexpensive addition.

PARTICULARS

SIZE.	Amperes at 1,000 per square inch at above ratio, Loss = approx. 2½ volts per 100 yards.	Amperes at I.E.E. Standard.	DIAMETER.	AREA.
S.W.G.			Inches.	Square Inches.
22	0·6158	1·7	·028	·0006158
21	0·8042	2·2	·032	·0008042
20	1·0179	2·6	·036	·001018
19	1·2566	3·2	·040	·001257
18	1·8096	4·2	·048	·001810
17	2·4630	5·4	·056	·002463
16	3·2170	6·8	·064	·003217
15	4·0715	8·2	·072	·004072
14	5·0265	9·8	·080	·005027
13	6·6476	12·4	·092	·006648
12	8·4949	15·0	·104	·008495
11	10·568	18·0	·116	·01057
10	12·868	21·0	·128	·01287
9	16·286	27·0	·144	·01629
8	20·106	31·0	·160	·02011
7	24·328	36·0	·176	·02433
6	28·952	42·0	·192	·02895
5	35·298	48·0	·212	·03530
4	42·273	57·0	·232	·04227
3	49·875	64·0	·252	·04988
2	59·828	75·0	·276	·05982
1	70·685	85·0	·300	·07069
1/0	82·447	97·0	·324	·08245
2/0	95·114	108·0	·348	·09511
3/0	108·68	120·0	·372	·1087
4/0	125·66	135·0	·400	·1257
5/0	146·57	155·0	·432	·1466
6/0	169·09	173·0	·464	·1691
7/0	196·34	196·0	·500	·1963

OF CONDUCTORS.

STANDARD RESISTANCE AT 60° Fahr.		STANDARD WEIGHT.		SIZE.
Ohms per 1,000 Yards.	Ohms per Mile.	Pounds per 1,000 Yards.	Pounds per Mile.	S.W.G.
39·05	68·72	7·120	12·53	22
29·90	52·62	9·301	16·37	21
23·62	41·57	11·77	20·72	20
19·13	33·67	14·53	25·58	19
13·28	23·38	20·93	36·83	18
9·762	17·18	28·48	50·12	17
7·478	13·16	37·20	65·47	16
5·904	10·39	47·09	82·87	15
4·784	8·419	58·13	102·3	14
3·617	6·366	76·88	135·3	13
2·831	4·982	98·24	172·9	12
2·275	4·004	122·2	215·1	11
1·868	3·228	148·8	261·9	10
1·476	2·598	188·4	331·5	9
1·195	2·104	232·5	409·2	8
·9881	1·739	281·3	495·1	7
·8307	1·462	334·7	589·1	6
·6813	1·199	408·2	718·4	5
·5688	1·001	488·8	860·2	4
·4821	·8484	576·7	1015·0	3
·4019	·7073	692·0	1218·0	2
·3402	·5987	817·6	1439·0	1
·2917	·5133	953·4	1678·0	1/0
·2528	·4450	1099·0	1935·0	2/0
·2212	·3893	1257·0	2212·0	3/0
·1913	·3367	1453·0	2558·0	4/0
·1640	·2887	1695·0	2983·0	5/0
·1422	·2503	1955·0	3441·0	6/0
·1225	·2156	2270·0	3995·0	7/0

PARTICULARS OF CONDUCTORS.

Number of Strands in Conductor.	DIAMETER OF EACH STRAND.		CARRYING CAPACITY.		EFFECTIVE SECTIONAL AREA OF CONDUCTOR.	CALCULATED WEIGHT OF CONDUCTOR.		CALCULATED RESISTANCE AT 60° FAH. STANDARD OHMS.	
	Legal Standard Gauge.	Inches.	Amperes at 1,000 per sq. inch, loss = approx. 2¼ volts per 100 yards.	Amperes at I.E.E. Standard.	Square Inches.	Per Statute Mile.	Per 1,000 Yards.	Per Statute Mile.	Per 1,000 Yards.
						lbs.	lbs.		
3	25	·020	·924	2·452	·0009240	19·57	11·12	45·780	26·0100
3	24	·022	1·118	2·868	·0011180	23·67	13·45	37·840	21·5000
3	23	·024	1·330	3·307	·0013300	28·17	16·01	31·810	18·0700
3	22	·028	1·812	4·258	·0018120	38·35	21·79	23·350	13·2700
3	21	·032	2·366	5·301	·0023660	50·08	28·45	17·880	10·1600
3	20	·036	2·994	6·444	·0029940	63·38	36·02	14·130	8·0290
3	19	·040	3·697	7·644	·0036970	78·25	44·47	11·450	6·5040
3	18	·048	5·323	10·310	·0053230	112·70	64·02	7·948	4·5160

7	25	·020	2·162	4·921	·0021620	45·52	25·87	19·570	11·1200
7	24	·022	2·616	5·751	·0026160	55·07	31·29	16·170	9·1900
7	23	·024	3·114	6·636	·0031140	65·54	37·24	13·590	7·7210
7	22	·028	4·238	8·543	·0042380	89·22	50·70	9·983	5·6720
7	21½	·030	4·864	9·565	·0048640	102·40	58·19	8·700	4·9460
7	21	·032	5·535	10·630	·0055350	116·50	66·21	7·644	4·3430
7	20½	·033	5·886	11·190	·0058690	123·90	70·41	7·188	4·0840
7	20	·036	7·005	12·900	·0070050	147·50	83·81	6·040	3·4310
7	19	·040	8·649	15·340	·0086490	182·10	103·50	4·892	2·7790
7	18	·048	12·460	20·680	·0124600	262·20	149·00	3·398	1·9300
7	17	·056	16·950	26·620	·0169500	356·90	202·80	2·495	1·4180
7	16	·064	22·140	33·120	·0221400	466·10	264·80	1·911	1·0860
7	—	·068	25·000	36·410	·0250000	526·00	299·00	1·693	·9618
7	15	·072	28·030	40·220	·0280300	590·00	335·00	1·510	·8578

PARTICULARS OF CONDUCTORS—*continued.*

Number of Strands in Conductor.	Diameter of each Strand.		Carrying Capacity.		Effective Sectional Area of Conductor.	Calculated Weight of Conductor.		Calculated Resistance at 60° Fah. Standard Ohms.	
	Legal Standard Gauge.	Inches.	Amperes at 1,000 per sq. inch, loss = approx. 2¼ volts per 100 yards.	Amperes at I.E.E. Standard.	Square Inches.	Per Statute Mile.	Per 1,000 Yards.	Per Statute Mile.	Per 1,000 Yards.
						lbs.	lbs.		
7	14	·080	34·59	47·80	·03459	728·0	414·0	1·2230	·6949
7	13	·092	45·75	60·10	·04575	963·1	547·3	·9249	·5255
7	—	·095	50·00	63·00	·05000	1027·0	584·0	·8672	·4928
7	12	·104	58·45	73·47	·05845	1231·0	699·3	·7238	·4112
7	11	·116	72·72	87·90	·07272	1531·0	870·0	·5817	·3305
7	10	·128	88·55	103·30	·08855	1864·0	1059·4	·4778	·2715
19	22	·028	11·48	19·36	·01148	242·5	137·8	3·6860	2·0940
19	21	·032	15·00	24·09	·01500	316·8	180·0	2·8220	1·6030

19 19	20 19	·036 ·040	18·99 23·43	29·33 34·74	·01899 ·02343	401·0 495·0	228·0 281·0	2·2290 1·8060	1·2666 1·0260
19 19	18 17	·048 ·056	33·75 45·93	46·85 60·33	·03375 ·04593	713·0 970·0	405·0 551·0	1·2540 ·9214	·7125 ·5234
19 19	— 16	·058 ·064	50·00 60·00	63·53 75·06	·05000 ·06000	1041·0 1267·0	591·0 720·0	85·88 ·7050	·4880 ·4007
19 19	15 14	·072 ·080	75·00 93·72	91·12 108·30	·07500 ·09372	1604·0 1981·0	911·0 1125·0	·5574 ·4513	·3167 ·2565
19 19	— 13	·082 ·092	100·00 125·00	112·10 136·20	·10000 ·12500	2080·0 2619·0	1182·0 1488·0	·4294 ·3415	2·440 ·1940
19 19	— 12	·101 ·104	150·00 158·40	157·90 166·40	·15000 ·15826	3156·0 3346·0	1793·0 1901·0	·2834 ·2671	·1610 ·1518
19 19	11 10	·116 ·128	197·10 240·00	199·20 234·00	·19710 ·24000	4163·0 5069·0	2366·0 2880·0	·2147 ·1764	·1220 ·1002
37 37	20 19	·036 ·040	36·94 45·60	50·47 61·07	·03694 ·04560	781·2 964·5	443·9 548·0	1·1450 ·9279	·6508 ·5272

PARTICULARS OF CONDUCTORS—*continued.*

Number of Strands in Conductor.	DIAMETER OF EACH STRAND.		CARRYING CAPACITY.		EFFECTIVE SECTIONAL AREA OF CONDUCTOR.	CALCULATED WEIGHT OF CONDUCTOR.		CALCULATED RESISTANCE AT 60° FAH. STANDARD OHMS.	
	Legal Standard Gauge.	Inches.	Amperes at 1,000 per sq. inch, loss = approx. 2½ volts per 100 yards.	Amperes at I.E.E. Standard.	Square Inches.	Per Statute Mile.	Per 1,000 Yards.	Per Statute Mile.	Per 1,000 Yards.
						lbs.	lbs.		
37	18	·048	65·68	80·91	·06568	1389	789	·6442	·3660
37	17	·056	89·38	104·20	·08938	1891	1074	·4735	·2690
37	16	·064	116·80	129·60	·11680	2469	1403	·3623	·2059
37	15	·072	150·00	157·30	·15000	3125	1776	·2863	·1627
37	14	·080	182·40	187·00	·18240	3859	2192	·2323	·1318
37	—	·082	200·00	194·00	·20000	4054	2303	·2207	·1254
37	13	·092	250·00	235·20	·25000	5103	2900	·1755	·0997
37	—	·101	300·00	272·00	·30000	6150	3494	·1455	·0827

37	12	·104	308·32	287·40	·30832	6521	3705	·1373	·0780
37	—	·110	350·00	313·50	·35000	7295	4145	·1227	·0697
37	11	·116	383·50	343·90	·38350	8111	4609	·1104	·0627
37	—	·118	400·00	350·00	·40000	8395	4770	·1067	·0606
37	10	·128	467·00	404·20	·46700	9878	5612	·0906	·0515
61	16	·064	192·45	195·40	·19245	4071	2314	·2199	·1249
61	15	·072	243·57	237·00	·24357	5153	2928	·1737	·0987
61	14	·080	300·70	281·60	·30070	6362	3615	·1407	·0799
61	13	·092	400·00	354·30	·40000	8414	4781	·1065	·0605
61	—	·098	450·00	390·00	·45000	9548	5425	·0938	·0533
61	—	·101	500·00	425·00	·50000	10140	5762	·0883	·0502
61	12	·104	508·20	433·10	·50820	10750	6109	·0833	·0473
61	—	·108	550·00	458·20	·55000	11600	6588	·0772	·0439
61	—	·110	600·00	472·00	·60000	12030	6836	·0744	·0423
61	11	·116	632·20	518·20	·63220	13375	7600	·0669	·0380

PARTICULARS OF CONDUCTORS—*continued.*

Number of Strands in Conductor.	Diameter of each Strand.		Carrying Capacity.		Effective Sectional Area of Conductor.	Calculated Weight of Conductor.		Calculated Resistance at 60° Fah. Standard Ohms.	
	Legal Standard Gauge.	Inches.	Amperes at 1,000 per sq. inch, loss = approx. 2¼ volts per 100 yards.	Amperes at I.E.E. Standard.	Square Inches.	Per Statute Mile.	Per 1,000 Yards.	Per Statute Mile.	Per 1,000 Yards.
						lbs.	lbs.		
61	—	·118	650·0	529·7	·6500	13840	7865	·0647	·0368
61	10	·128	769·7	609·0	·7697	16290	9254	·0549	·0312
91	13	·092	600·0	489·0	·6000	12558	7135	·0713	·0405
91	—	·098	700·0	542·0	·7000	14240	8094	·0628	·0357
91	—	·101	750·0	570·0	·7500	15130	8597	·0591	·0336
91	12	·104	800·0	598·0	·8000	16040	9115	·0558	·0317
91	—	·108	850·0	636·0	·8500	17300	9833	·0518	·0294
91	—	·110	900·0	655·0	·9000	17950	10200	·0498	·0283
91	11	·116	942·9	719·3	·9429	19960	11340	·0449	·0255
91	—	·118	1000·0	735·0	1·0000	20650	11730	·0433	·0246
27	—	·101	1000·0	748·0	1·0000	21120	12000	·0424	·0241

The tables given on the foregoing pages are based on the following resolutions adopted by the Engineering Standards Committee:—

That a wire one metre long, weighing one gramme and having a resistance of 0·1508 standard ohms at 60° F. (15·6° C.), be taken as the Engineering Standards Committee (E. S. C.) standard for annealed high conductivity commercial copper.

That copper be taken as weighing 555 lbs. per cubic foot (8·89 grammes per cubic centimetre) at 60° F. (15·6° C.) which gives a specific gravity of 8·89.

That the average temperature co-efficient of 0·00238 per degree F. (0·00428 per degree C.) be adopted for commercial purposes.

That 2 per cent. variation from the adopted standard of resistance be allowed in all conductors.

That 2 per cent. variation from the adopted standard of weight be allowed in all conductors.

That an allowance of 1 per cent. increased resistance, as calculated from the diameter, be allowed on all tinned copper conductors between diameters, 0·104″ and ·028″ (Nos. 12 and 22, S.W.G.) inclusive.

CHAPTER V

UNDERGROUND CABLES AND FITTINGS

We now come to one of the most important sections of this treatise, namely, the consideration of underground wiring systems. There are three distinct classes of cables to be considered :—(*a*) Shaft cables, (*b*) Roadway, or inbye cables and (*c*) Flexible or trailing cables.

The shaft cables require to be well armoured and insulated with non-hygroscopic materials (or should hygroscopic materials be used special precautions must be taken to prevent access of moisture). For underground distribution of power from the shaft into the workings, armoured cables are not, in many cases, absolutely necessary, but the insulation must still be non-hygroscopic and capable of resisting mechanical damage. For the flexible or trailing cables, employed in connecting such portable machinery as coal cutters, rock drills, etc., with the distributing mains, twin or three-core cables are recommended (according to whether the system is continuous current or three-phase) and these cables are usually rubber insulated and finished, overall, with a flexible protective covering.

In considering the class of cable to be used for underground colliery work, it will be evident that the conditions differ largely from, say, those of a town lighting system, and it is only a thorough appreciation of the special difficulties met with in this class of work that has enabled the various makers to evolve a suitable class of cable.

The chief trouble experienced is perhaps that due to the presence of water, which in some cases may be acid, or contain chemical salts in sufficient quantities to seriously damage the cables unless suitable protection be afforded. Another trouble is the liability to mechanical damage, either through such accidents as trucks fouling the cables, or a roof falling, and bringing them down with it.

Dealing first with the insulating medium, we find that rubber will give us practically all we require; but rubber-covered cables, of large size, are expensive, and may cost double the price of similar cables insulated with paper, bitumen, etc. Paper-insulated lead-covered cables have been used for many years in connexion with town lighting schemes, but as this class of insulation is very hygroscopic, trouble has occurred due to moisture penetrating, and breaking down the insulation. To guard against this, impregnated paper has been employed with considerable success, but it is still necessary to take great care that moisture does not enter, and for this purpose, cable boxes must always be used at the end of a line for making connexions.

The insulation most favoured for colliery cables is that known as vulcanized bitumen. This substance is non-hygroscopic, and also possesses the necessary insulating qualities. Being quite moisture-proof, the lead covering, used with paper insulated cables, is not required. Some of the earlier bitumen cables gave trouble, due to decentralization of the conductor when the bitumen is softened by heat, as may occur when a cable is subjected to a heavy overload. For this reason some makers now supply cables with a paper separator between the conductor and the bitumen.

We will now consider, briefly, the type and class of cable to use for any particular position or system of supply. First we will take the case of shaft cables. These can be made up in the form of single, twin, or concentric cables for continuous current working, whilst for three-phase we may employ three single cables, or, alternatively, a three-core cable.

For continuous current, single cables are preferred. The conductor may consist of a strand of high conductivity copper wires, which should be tinned if vulcanized bitumen is used as insulation, otherwise the sulphur in the bitumen may attack the copper. Some makers provide a strand filling substance, a waterproof compound, which renders it practically impossible for water to travel along the interstices of the strand. The stranded conductors are sheathed with a solid tube of bitumen, under high pressure, then taped with two or more coats of stout tape, lapped on spirally in reverse directions, and thoroughly impregnated with a bituminous preservative compound, and afterwards braided or armoured as the case may require. A three-core cable would be prepared in the same way; but, after taping, the three cores are laid up together, the spaces being filled in with jute fibre (or with bitumen); the whole is then further sheathed with bitumen, taped with two or more bitumen tapes, and afterwards braided and compounded, or armoured, according to the conditions under which it is to be used.

As already stated, for conductors down the shaft two single cables are preferred for continuous current working. This method might also be employed with advantage for three-phase working, especially when the sectional area of the conductor is large. It will be seen that a three-core cable is naturally of considerable diameter, as compared with single cables, and an armoured shaft cable to transmit 400 amperes may be as much as 3½ inches diameter overall. These large cables are difficult to handle, and, what is perhaps more important, it is impossible to manufacture them in unbroken lengths for very deep pits.

If single cables are used for alternating current work they must not on any account be armoured, otherwise there will be an alternating magnetic field set up in the steel armouring, which will cause pressure drop and consequent loss of energy. For this reason, when single cables are used for alternating current they are merely braided, and treated with preservative compound. If it be necessary to protect such cables in the shaft against mechanical damage, casing or troughs must be provided and this, of course, entails expense.

For shaft work a three-core cable is generally used for three-phase current, and, if owing to the large area required, and the great depth of shaft, it is found impossible to manufacture and handle in one length, it will be advantageous to split up the cable into two, or more, distinct three-core cables each of smaller sectional area, so that the two or three cables together will be used for transmitting the total load. Such a scheme has the additional advantage of allowing one cable to be laid off at a time for test, or, in the event of anything going wrong, the most important motors and lights underground can be kept going while one of the cables is being repaired.

For very wet shafts lead covered cables have been employed, but, owing to the great weight of the lead, this method is impossible in deep shafts when the cable is hung or supported only at infrequent intervals. If trouble due to a wet shaft is expected, and lead-covered cable is out of the question, it will be well to employ a bitumen insulated cable, strand filled, wormed and sheathed with solid bitumen instead of jute yarn.

Shaft cables, unless run in casing or troughing down the pit, should always be double-wire armoured, with one exception, as a protection against mechanical damage. The cable, either single (continuous current) or three-core, should be armoured with two layers of galvanized steel wires, laid on in opposite directions, the whole being then covered, overall, with tarred jute yarn, and treated with preservative compound. This outer covering is merely to protect the galvanized steel wire armouring from corrosion.

When cables are suspended vertically in the shaft, the steel wire armouring takes the strain, and supports the weight of the complete cable. The usual method of supporting cables in pit shafts is by means of hard wood cleats, about 4 feet long, spaced from 20 to 40 yards apart. One of these cleats (by Messrs. Callender) is shown in Fig. 13, *A*, fixed to a brick-work shaft by means of rag bolts. Such a cleat can be arranged to carry one, two, or more cables as required. Where this method of suspension is inadmissible, the cleats may be hung on chains, as shown in Fig. 13, *B*, the chains being attached to hook rag bolts, let into the brickwork, or fixed in such manner as may be most convenient.

Another method of suspending a shaft cable is through the medium of a special form of steel suspender at the top of the shaft, designed to take the whole weight of the cable. Such a suspender, by Messrs. Siemens Bros., is shown in Fig. 13, *C*. With this arrangement it is absolutely necessary to effectively secure the steel wire armouring at the point of suspension, for this must carry all the weight. The method can be used, without any further support for shafts up to 400 feet in depth; for deeper shafts it will be necessary to add suspension cleats.

There is one other type of shaft cable that must be mentioned before leaving this part of the subject: namely, "Manilla cord armoured" cable. These are usually of the vulcanized bitumen type, but, instead of steel wire armour, we have a double layer of hard manilla cords, wound in reverse directions. This covering is waterproof, and has the advantage of being much lighter than steel-armoured cables; but the most important point is that separate single-core cables, of large carrying capacity, can be made

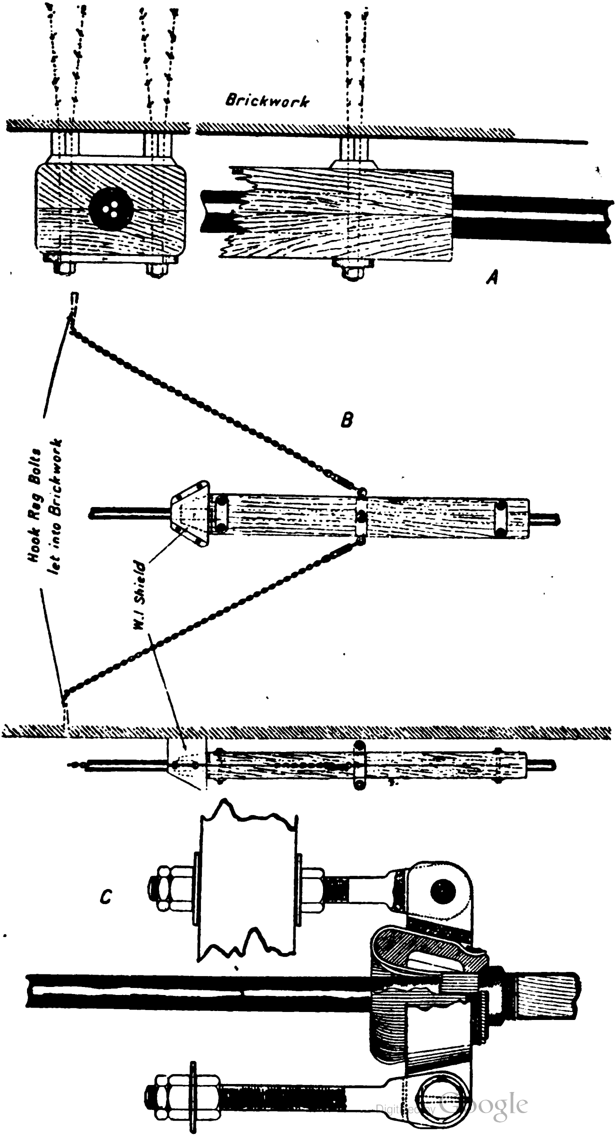

FIG. 13. SHAFT CABLE SUSPENDERS.

in unbroken lengths, and used for three-phase working without the loss of pressure and energy which would occur if steel wire armoured cables were used under similar conditions.

The lower end of the shaft cable usually terminates in a switch box and distribution board, from which smaller cables are run for distributing electrical energy to the various motors used underground.

These cables in the underground roads are made up and insulated like the mains haft cables described above; but if steel wire armouring be employed, one layer only is sufficient in most cases. If the cable is in a position where frequent falls of the roof are experienced, double wire armouring may be employed, or, in special cases, we may have what is known as lock-coil armouring, which consists of steel wires of special section so arranged as to fit into one another and form practically a solid sheath of steel. This form of armour is somewhat expensive, and would only be used when great mechanical strength is necessary; it is the strongest armour yet devised for cable protection. Many colliery engineers prefer unarmoured cables for distribution in the roads, and there is something to be said for this arrangement in the case of small installations, when maintenance is in more or less unskilled hands. There are several methods of fixing underground road cables, and the illustration (Fig. 14) prepared by the St. Helens Cable Company shows four methods at present in vogue.

The first consists of single unarmoured cables, taped, jute yarned, and braided, laid, either on a shelf cut in the wall, or in a trough behind the props; the trough should, if possible, be filled with bitumen. This method is rather expensive, but very safe, as there is no risk of personal contact.

The second consists of unarmoured single cables, suspended with tarred twine, behind the props, or, where the roof is good, laid on a shelf cut in the side.

The third consists of armoured cables, single for continuous, twin for alternating, and three core

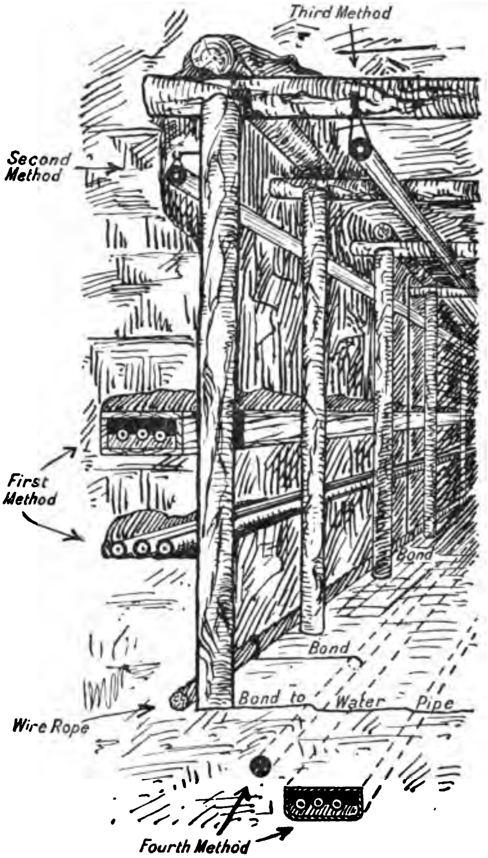

FIG. 14. METHOD OF RUNNING CABLES IN ROADS.

for three phase, suspended either from the props (in front) or from the roof timbers.

The fourth consists of armoured cables laid direct in the floor, or unarmoured cables laid in troughing in the floor. This is a most excellent method, but very expensive, and upsets the working of the road; provision must also be made for a rising floor by leaving slack in brick chambers near the joint boxes.

Where armoured cables are used in a road it is absolutely essential that the armouring should be continuous, and remain so, all branches and repairs being bridged over in a substantial manner with copper or iron strand, firmly clamped to the armouring. No mere twisting of one wire round the armour to be allowed. Further, the armour should be substantially earthed, every hundred yards, to water pipes. If there are no water pipes in that particular road, an old steel rope should be laid in the floor to take its place, the rope being connected to water pipes at the nearest point. All machines, motors, winding gears, etc., should be earthed in the same manner. This frequent earthing is necessary, as the bridging of the armour at repairs and joints may become defective in time, and damage in that length would render the armour alive.

Armouring is undoubtedly useful in saving the insulation from small damage, but under a severe blow, piercing the insulation, a flash results before the fuses have time to blow; with unarmoured cable there is no flash since the leakage at the fault is only two or three amperes; but if this leak is not repaired, smouldering may ensue. After every fall of roof, therefore, the cables should be carefully examined and any damaged spots repaired. The mine electrician should also test the insulation of the cables themselves, all motors being disconnected; he must not be content with a fairly high insulation, but must insist on the same value as obtained before the fall, or find out the reason for the decrease.

When cables are suspended from the roof timbers it is usual to employ raw hide, or metal suspenders. These are easily fixed, and a length of cable can be suspended in a very short time. When frequent falls are experienced, flexible suspenders may be used. Fig. 15 shows a type of flexible suspender, known as the Callender-Ward patent. With this arrangement the cable is safely supported so long as the suspender has to deal with its weight alone but in the event of any undue pressure coming on the cable, the suspender allows it to drop, and possibly escape such damage as might occur if it were rigidly held.

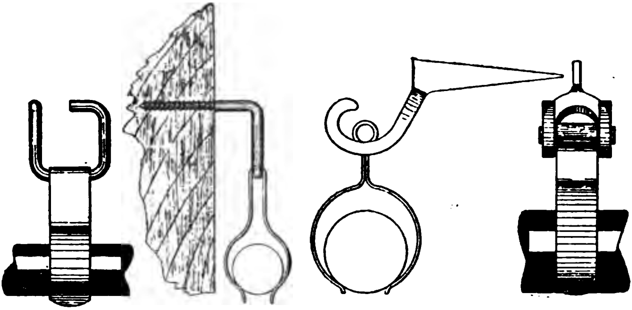

FIG. 15. FLEXIBLE CABLE-SUSPENDER.

With a cable system underground in a mine, where we have one or more main and sundry smaller distributing cables, we shall require joint and disconnecting boxes somewhat similar to those used for town lighting. The conditions under which these boxes are used in mines present many special difficulties which are not met with in ordinary surface installations, and consequently a special study has been made of the subject of suitable and efficient junction boxes for mine use.

Fig. 16 shows a standard straight-through joint

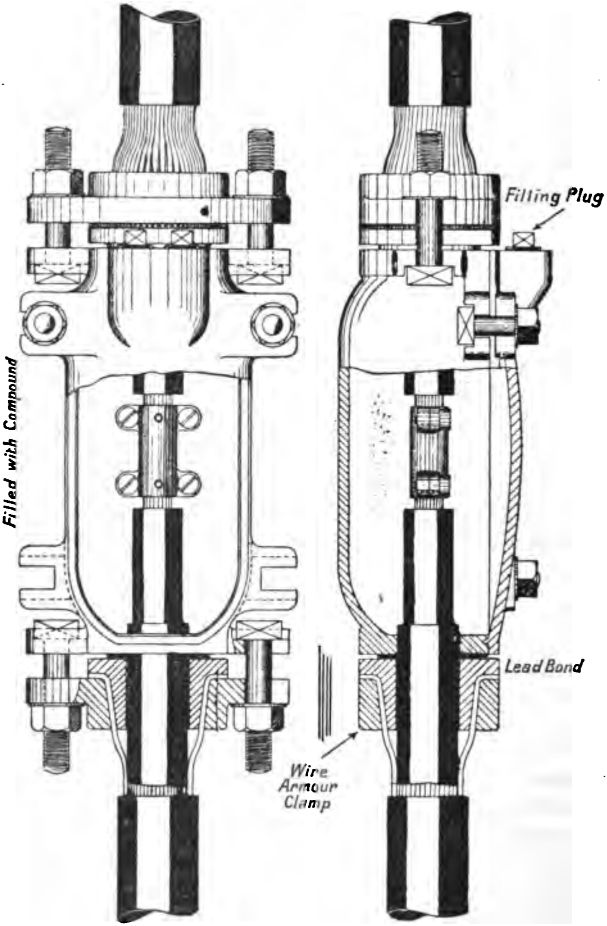

Fig. 16. Shaft Cable Junction Box.

box for jointing single cables in vertical pit shafts when necessary, and Fig. 17, *A*, shows a similar box for three-core cable in horizontal pit roads.

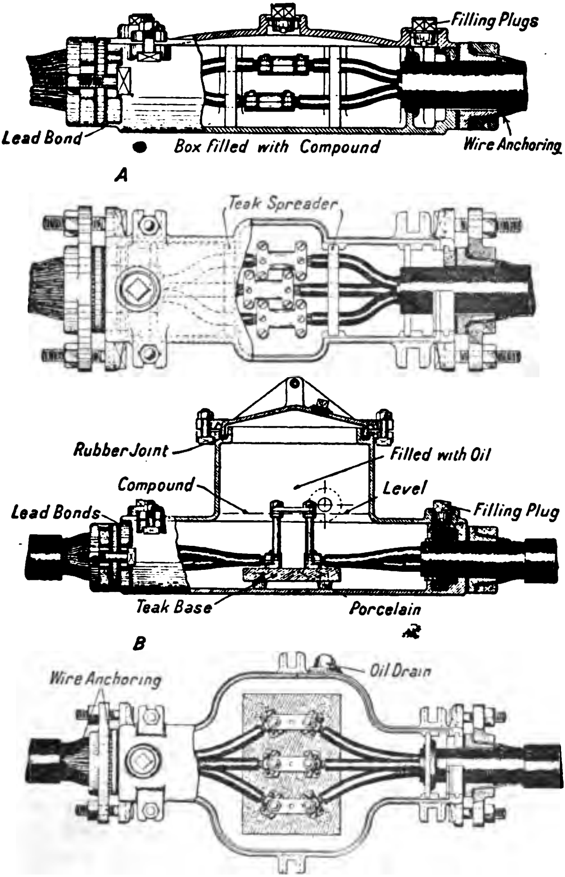

FIG. 17. ROAD CABLE JUNCTION BOXES.

Fig. 17, *B*, is an example of a disconnexion box for three-core cable whilst Fig. 18, *A*, shows a three-way network box with disconnecting links. A four-way box, when necessary, would be designed on similar lines. Another type of box often required

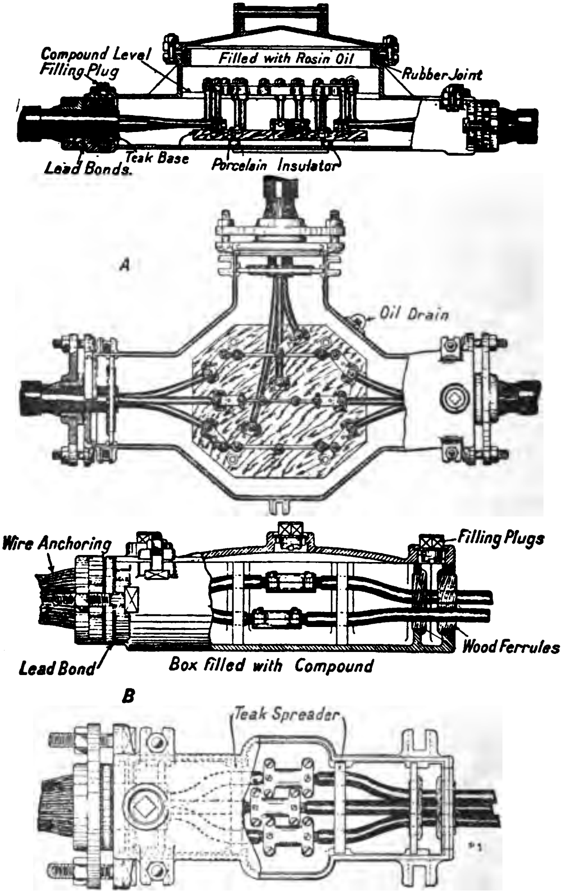

FIG. 18. ROAD CABLE JUNCTION BOXES.

in connexion with three-core cables is shown in Fig. 18, *B*, and is known as the trifurcating box because it divides up the three cores of a main cable into three separately insulated conductors. This form of box is used at the end of a three-core cable as it affords a neat and effective means of bringing out the conductors for connexion to the switchboard. These illustrations are all of Messrs. Callender's standard boxes.

It will be noticed that in all these boxes the joints are dry, as in many cases it would be impossible to solder the connexions in the mine. The disconnecting boxes are also shown with hermetically sealed lids, and are filled with compound to a certain level, and above this again, with resin oil, in order to prevent sparking when connexion or disconnexion of a cable is effected. In some few cases it is impossible to use compound in the boxes as it may be inadmissible to heat it in the pit or to convey it heated from the surface. In such cases a special high insulating grease can be used, which, while being sufficiently soft to apply without heating, is too stiff to permeate the cable dielectric if of paper or jute, or to be drawn up the strands of the conductors. Oils are not recommended for this reason and are only used on the top of a more solid sealing compound as a spark preventative. The boxes are shown with armour clamps for use with wire armoured cables, to ensure electrical continuity through the joints, but these clamps would be omitted in the event of the cables being unarmoured.

When electric motors are used in the mine for operating portable machines such as coal cutters, drills, etc., they are connected up by a flexible conductor technically known as a trailing cable. As many accidents which occur have been traced to the use of such portable machinery and trailing cables, it has become necessary to devote special attention to the subject. The conditions are exceptionally severe, and the trailing cable is often dragged over rough places where sharp projections are met, or subjected to damage from falls of roof or dropped tools. Sometimes the cable may be struck by a pick or shovel, and all these contingencies have to be guarded against.

Trailing cables usually embody conductors of fine drawn, high conductivity, tinned copper wires stranded together to form a flexible whole, and insulated with pure Para and vulcanized indiarubber, the radial thickness of the dielectric being greater than that usually allowed for a given working pressure. The insulated cores are then laid up together (two for continuous current working and three for three-phase) with wormings of yarn and covered overall with a flexible protective braid or armour.

The Home Office rules require trailing cables to be specially flexible, heavily insulated, and protected with either galvanized steel wire armouring, extra stout braiding, hose pipe, or other effective covering. Among cables of the non-armoured class we find protective coverings consisting of—(*a*) Mattress twine braided and compounded; (*b*) Hard core braid, specially manufactured to prevent unravelling when cut; (*c*) Compounded hard core braid, interlaced with galvanized steel wires, which gives a smooth surface, and is less bulky than most other coverings; (*d*) Raw hide or leather braid; (*e*) Wrapping of stout marline; (*f*) Rubber insulated cables drawn into stout rubber hose pipe or flexible metallic tube. In some cases, for continuous current working, two separately insulated and protected cables are employed, laid side by side and bound together at intervals of a yard with stout tarred mattress twine.

With the above non-metallic form of protection there is no question of earthing, and, as a matter of fact, the Home Office rules do not call for the earthing of portable motors or trailing cables, even if the latter be armoured. For this reason one of the most serious difficulties colliery engineers have to contend with is the risk of shock owing to a portable motor becoming alive. It is difficult to maintain an efficient and effective earth connexion with machines that are always being moved about. Some engineers prefer to earth their machines by means of a wire laid up in the flexible trailing cable, and such cables are provided with an extra core for connecting to the frame of the motor, this core being efficiently earthed at another point.

The Home Office rules require that a terminal box shall be provided at all points where flexible conductors are joined to main cables, and that a switch shall be fixed close to, or in the terminal box, capable of entirely cutting off the supply from the terminal box and motor. These terminal boxes are known as gate-end boxes and it is essential that they be properly designed, otherwise there is risk of accident. The three essential points in connexion with the design of a satisfactory gate-end box are :—

(*a*) Easy connexion and disconnexion of the main cable; (*b*) Efficient and satisfactory switch and fuse gear; (*c*) Facilities for the ready connexion and exchange of the trailing cable.

Such a box, designed by Messrs. Callender, is shown in Fig. 19, and it will be noticed that the main cable is brought in at the righthand side, and the three cores connected by couplings to three copper rods, which pass through glands to the fuse terminals in the main chamber. The coupling chamber is provided with an independent lid, which, when in position, makes an airtight joint and obviates the use of compound. The main chamber contains the switch and fuse, the former being operated by a removable handle, and so arranged that if a fuse blows it is impossible to renew it with the switch "on"; further, owing to special interlocking gear it is impossible to remove the lid of the chamber before first opening the switch. The main chamber is filled with resin oil which prevents sparking when a fuse blows. The trailing ends are designed for rapid connexion and disconnexion to the main chamber;

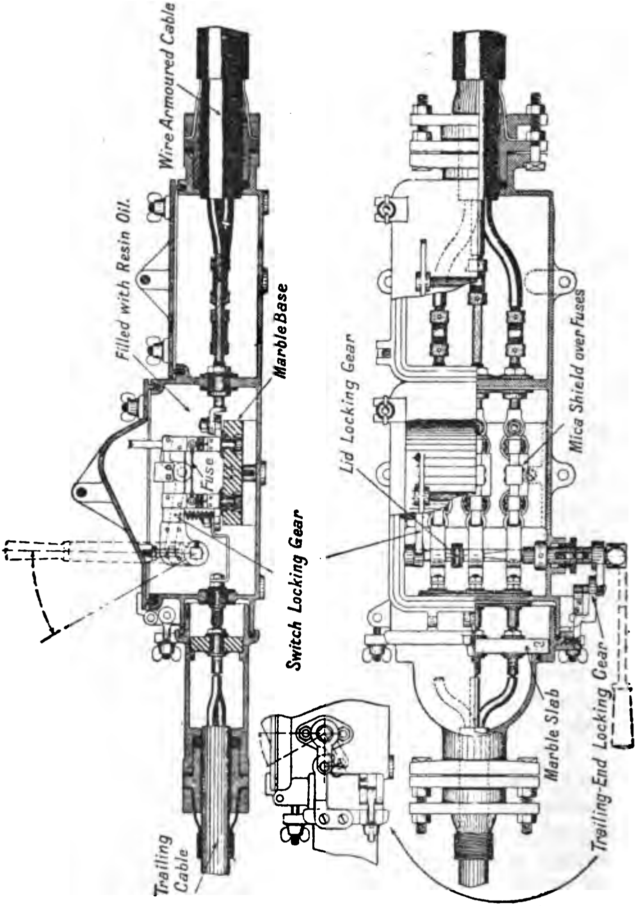

FIG. 19. CALLENDER'S GATE-END BOX.

but owing to the interlocking arrangement, the trailing end cannot be inserted or removed unless the switch is "off," thus making it impossible to produce a spark by negligence in manipulating the box.

Another type of gate-end box is shown in Fig. 20 and is designed for use with Fisher's patent protective system. In addition to the requirements above referred to, this gate-end box has several automatic features, designed to prevent any possibility of accident, even in the hands of the most careless operator. It will automatically interrupt the supply in the event of—(*a*) Persistent overload; (*b*) Short-circuit between phases; (*c*) A fault between any phase and earth; (*d*) No voltage or failure of supply; (*e*) A break or bad contact in the earth circuit. The gate-end switch cannot be closed unless the earth connexion is complete, and it may be opened by operating a small lever attached to the coal cutter or other portable machine.

The Fisher system involves the use of a trailing cable having a pilot or subsidiary wire, in addition to an earth conductor.

The gate-end switch is controlled by a solenoid in circuit with the pilot and earth conductor, so that, if the earth circuit is incomplete, current cannot pass through the solenoid, and it is impossible to close the switch.

Fig. 20 shows the arrangement for a three-phase supply with earthed neutral.

When the operating switch is closed (provided the pilot circuit and the earth conductor are completed through the framework of the machine), the solenoid *P* is energized and the main switch closed. On releasing the handle of the control switch, the switch springs automatically on to its contact which puts a high-resistance solenoid in circuit, and also effects a change-over by which the connexion through the solenoid is taken from the outgoing side of the switch. It will be seen that the main switch cannot be held in the closed position unless current passes through the solenoid, and there will be no circuit through the solenoid unless the earth circuit is com-

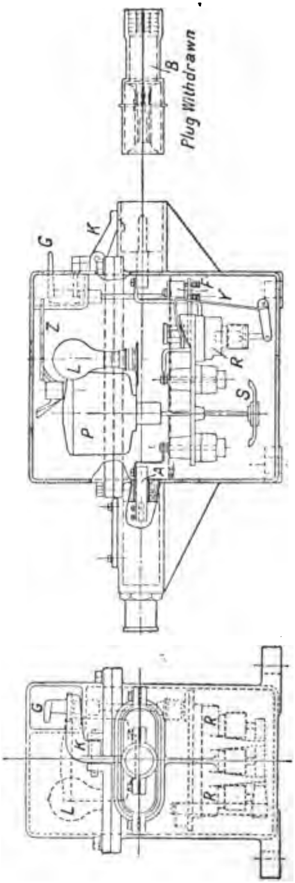

FIG. 20. FISHER'S PATENT GATE-END BOX AND PLUG.

plete, or if the supply voltage fails. By this means the switch opens automatically under the fault conditions enumerated above.

S is a three pole oil-break switch fitted with three overload release coils *R*, *R*, *R*, governed by a time-lag device of the oil dash-pot type. A scale, *Y*, is provided for adjusting the setting of this overload arrangement.

P is the controlling solenoid, and has two windings, one of which is used to give a maximum pull at the moment of closing the switch, whilst the other is a coil of high resistance, consuming only the small amount of energy sufficient to hold up the armature, when the switch is "on," but the latter is knocked out by means of simple mechanism, when the weight of the armature is released by the solenoid.

F is a small control switch, operated from outside the box by the handle *G*. This control is on a free handle principle, i.e., in the event of a fault occurring the main switch is bound to trip out, even though the control switch is held by the operator, or if an attempt be made to tamper with the device.

L is an indicating lamp which, by the aid of a simple shutter device, is visible through a strong glass window, and gives a clear indication, which can be seen from outside, whether the switch is "on" or "off." The lamp is connected to the incoming cable, and, when no light is seen indicates that the supply is cut off from this source.

The overload release coils *R* and *R*, in operating, open the control circuit and so release the main switch. The complete mechanism is enclosed in a strong iron case. The current-breaking parts are immersed in oil. The case and lid have wide machined joints to avoid the possibility of an emission of flame. Mechanical terminals are provided throughout, so that joints can be made without soldering. Those at *A* take the incoming cable, the insulated ends of which are located in a box which can be run in solid with compound for the purpose of sealing the ends. Suitable glands are provided for earthing the armour thoroughly to the box. The trailing cable is attached to the plug *B*. The plug is enclosed in a strong cast-iron case, and is so interlocked with the control switch, that it is impossible to withdraw the plug when the main switch is closed. This interlocking is effected by the pawl *K*, and it is obviously impossible to draw out an arc in manipulating the plug because the latter cannot be withdrawn when the circuit is alive. A corresponding plug is used at the coal-cutter end of the trailing cable, and a socket is made, as shown in Fig. 21 suitable for fixing to any existing coal-cutter frame. Like the corresponding socket on the gate-end box, it carries a locking pawl inter-connected with a small switch, by which the men working the coal-cutter can open the control circuit, and so render the trailer and motor dead, and ensure that they cannot be again energized until the switch is closed at the coal-cutter end. The system enables a supply to be cut off, right back to the gate-end box, and not only disconnects the motor, but the trailing cable as well,

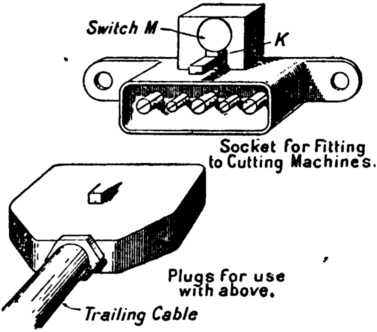
Switch M
K
Socket for Fitting to Cutting Machines.
Plugs for use with above.
Trailing Cable

FIG. 21. PLUG ; FISHER PATENT SYSTEM.

and at the same time prevents any one accidentally closing this circuit if the men at the coal-cutter are carrying out any work on the machine.

The plug is made reversible so that the motor can be reversed, if necessary, by simply withdrawing the plug and reinserting it the other way round.

It is obvious that, if the plug is not in the socket, the control circuit is incomplete, and it is thus impossible to close the main switch with the plug lying on the ground.

In reference to the question of earthing cable systems generally, it will be noticed that the Home Office rules do not enforce this for medium pressure, although it is insisted upon for high pressure working. It is quite an open question at the present time with colliery engineers, and some prefer unarmoured cable for use underground. In some respects this unarmoured unearthed cable is safer, if the installation is improperly maintained. When a fault occurs in an unarmoured cable, a severe shock can only be experienced at the actual fault, and, further, one may have a serious fault on one or more cables, and still be able to run without danger to life or property.

With metallic-armoured cables this would be impossible, because if an armoured cable be faulty the armouring is at the same potential as the conductor; if the armouring is connected to earth this can never be more than a few volts above earth potential. If, on the other hand, the armouring is not earthed, or if the earth connexion is faulty the pressure may be, say, 500 volts above earth potential, not only at the actual fault but all along the armouring. This is of course exceedingly dangerous and effective earthing is the only practical way of avoiding danger when armoured cables are used.

The armouring must not only be efficiently earthed but care must be taken to make it electrically continuous throughout. To this end all joint boxes should be arranged for clamping the armour as shown in Figs. 16, 17 and 18. In important installations it is sometimes the practice to lay an earth wire, or strand of copper wires, along the cable route and connect to it all the cable armouring as well as motor frames and auxiliary apparatus. This arrangement has great advantages over the ordinary system of earthing by way of the armouring only, since a break in a supply cable will be insufficient to destroy the earth connexion, and, further, the earth connexion of any particular section may be broken without affecting that of the remainder.

In connexion with the application of electricity for lighting in collieries, it will only be necessary to deal with a few special points. The subject of electric lighting is a broad one, and the reader is referred to other volumes in this series for details, both in connexion with arc and incandescent lighting.

The Home Office regulations require that all arc lamps shall be so guarded as to prevent pieces of incandescent carbon falling from them, and shall not be used in situations where there is likely to be danger owing to the presence of coaldust. They should be so screened as to prevent risk of contact.

Small wires for lighting circuits must be either carried in pipes or casings, suspended from porcelain insulators, or tied to them with some non-conducting material which will not cut the covering, and in such manner that they do not touch any timbering or metal work. On no account must staples be used. If metallic pipes are used they must be electrically continuous and earthed. If separate uncased wires are used they must be kept at least 2 in. apart, and not brought together except at lamps, switches, or fittings.

In any place or part of a mine to which General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, electric lamps, if used, must be of the vacuum or enclosed type; they must be protected by gastight fittings of strong glass, have no flexible cord connexions, and must only be changed by a duly authorized competent person. While the lamps are being changed the current must be switched off.

The electric lighting of surface works does not call for any special comment. Electric lighting underground, by means of incandescent lamps, may be arranged on the three-wire continuous-current system if the pressure lies between 250 and 500 volts, care being taken to distribute the lighting between the two sides of the system as equally as possible.

With three-phase working a step-down transformer would be used to obtain the most suitable pressure for lighting purposes. A three-phase step-down transformer for this purpose should be mesh connected on the primary side as shown in Fig. 5 (*b*) and star-connected on the secondary side as in Fig. 5 (*c*) the lighting circuits being arranged between the neutral and each outer or line wire. From such a three-phase transformer it will therefore be necessary to have three distributing circuits, and, although a perfect balance is not absolutely necessary, care should be taken to divide the load between the three circuits as equally as possible.

A transformer with mesh-connected primary and star-connected secondary is recommended, because this arrangement gives better balancing, but a cheaper combination may be used, consisting of an auto-transformer with star connexions, the main supply being connected to the outer terminals, and tappings provided on each limb, from which the low-tension current may be taken for lighting purposes. This arrangement is not so good from a balancing point of view, and, if adopted, special care must be taken to distribute the lighting over the three single-phase circuits as equally as possible.

In employing alternating current for lighting purposes it must be remembered that, with low frequencies, there may be trouble due to fluctuation in the lights. Arc lighting cannot be successfully carried out on a lower frequency than 40 cycles per second. Incandescent lighting is satisfactory with a frequency as low as 25 cycles per second for mine work, but low voltages (100–110 volts) are recommended, in order that the lamp filaments may be thick and short. The amount of fluctuation on low frequencies is less with a lamp having a short thick filament.

CHAPTER VI

ELECTRIC HAULAGE

One of the great advances in recent mining practice is the adoption of electric haulage, and in many cases this has become an absolute necessity in order to remove coal from the working faces and deliver it in the quantities required.

There are three distinct systems of haulage, known as (*a*) main rope haulage, (*b*) main and tail haulage, and (*c*) endless rope haulage (apart from the consideration of traction by locomotive), and the selection of any particular system depends entirely upon circumstances.

The main rope haulage usually consists of one drum, winding a single rope, and hauling the tubs up the gradient. This type of haulage gear can obviously only be used on roads having a continuous down gradient in the direction away from the gear, since the tubs are required to run back by gravity.

Fig. 22 shows a typical arrangement of this type

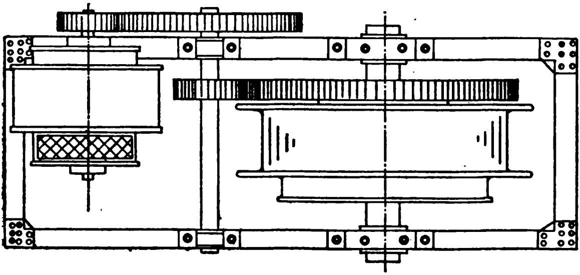

Fig. 22. Plan of Main Haulage Gear.

of gear which is, perhaps, the simplest. The motor usually drives through double reduction spur-gear, on to the drum shaft, and as it is usual to start up the motor by means of a controller, no friction clutches need be employed, but these are sometimes included if the starting conditions are severe, and in any case a clutch of the friction, or claw, type must be fitted for the purpose of disengaging the drum from the shaft, and allow the load to run back by gravity. It is not considered necessary to reverse the motor with this type of haulage, although, as explained later on, reversing controllers are often employed. A substantial brake gear must of course be fitted, capable of holding the maximum load on the incline.

The use of this type of haulage gear obviously depends upon the gradient of the roads, which should be at least 3 inches per yard for the system to work satisfactorily, although if the rails are light, and badly laid, it may be necessary for the gradient to be even steeper, to ensure satisfactory working.

In many instances it is impossible to obtain a continuous down grade in a direction away from the haulage, in which case the empty tubs cannot return by gravity, and a tail rope has to be employed for the purpose ; haulage gear arranged on this principle is known as " main and tail " haulage. The arrangement usually consists of two drums as shown in Fig. 23, one winding the main, and the other the tail rope. With this arrangement clutches are not absolutely necessary, although they may be employed if the starting conditions are severe, but in most cases the motor is provided with a reversing controller, capable of starting, stopping, reversing, and regulating the motor according to requirements. Brakes are fitted as usual.

The disadvantage of main and tail and also of main rope haulage is the time lost in working. On consideration it will be seen that, allowing time for the return of the empty tubs, and also for changing the tubs at each end of the run, the motor is only effectually working for about one-third of the total time. In cases, therefore, where time is important, and it is required to haul the maximum amount of material, a haulage of the endless rope type is used. With this gear two ropes (which form one endless loop) run continuously, the full tubs travelling up on the one rope and the empty tubs returning by the other, the gear running continuously for long periods. This system is very simple, but the roads must be fairly straight and also wide enough for the two lines of tubs to pass. Other advantages of this type of gear are that the material is delivered more regularly, and the power required to drive may be less, owing to the fact that the full and empty tubs tend to balance; further, owing to the comparatively slow speed at which the rope travels, the rails may be lighter than with main haulage or main and tail haulage gears.

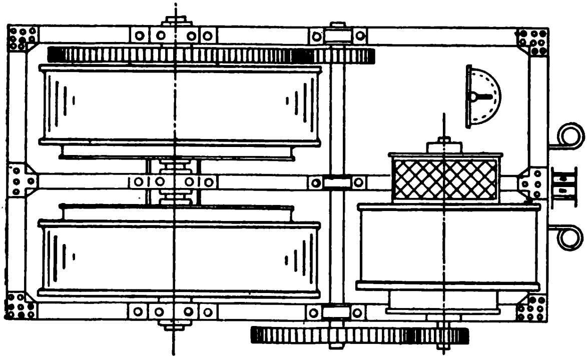

FIG. 23. MAIN AND TAIL HAULAGE GEAR.

Endless rope haulage gear is often made in a form similar to main haulage with single drum, this drum being of special shape with the rope passing round three or four times to ensure sufficient grip. Many types of drum have been designed for endless rope haulage gears, and in some cases a single grooved pulley is used.

The motors operating this type drive through single or double reduction gearing as usual on to the drum shaft, but the motor is not required to reverse, although a reversing controller is often supplied in connexion with such equipments. Occasionally haulages are designed with two, three, or even four rope drums, or wheels, for operating ropes on as many different routes. In this case the motor and gear run continuously, and any drum or wheel may be set in motion or stopped by a suitable friction clutch, efficient brakes being also provided on each drum.

In regard to haulage gears generally, the motors must be rated according to the requirements of each particular case, but broadly speaking, the following are usually considered correct.

Main rope haulage . .	Motor of one hour rating.
Main and tail rope haulage .	Motor of two hour rating.
Endless rope haulage . .	Motor of continuous rating.

By thus rating the motors in hours, we mean that the temperature rise must not exceed a certain specified figure, say, 75° F., after a run at normal full-load for the periods stated.

With continuous rated motors a period of six hours is usually considered sufficient for the purpose of a temperature test.

The reason for adopting motors of one or two hour rating is because such machines are only required to run for short periods at their rated load. In the case of a main haulage gear, the motor will run for a period at its full rated load, and then remain stationary, whilst the tubs return by gravity.

In the case of the main and tail haulage gear the motor will work for a period at its full rated load, then at a much smaller load when returning the empty trucks, and will remain stationary for some time while the tubs are changed.

If the motors operating the haulages are of the continuous-current variety, they are usually series wound, in order to obtain the maximum starting torque, but in other cases, such as endless rope haulage gears, operating no more than one rope, it is preferable to fit compound-wound motors in order that the speed may be maintained constant at all loads, a disadvantage of the series motor being that the speed increases on light load. If the supply is three-phase alternating, the haulage motors will be of the wound rotor type, with slip rings.

As regards the controlling equipment, it is usual to put in controllers of the tramway type, suitable for starting, regulating, and reversing. Such controllers are of the non-automatic type, for hand operation only, a suitable panel being also provided with automatic switches, having overload and no-volt attachments if necessary, together with such instruments as may be required.

Controllers for continuous-current motors are usually of the vertical tramway pattern, and are fitted with magnetic blow-outs to reduce sparking to a minimum.

For alternating current motors they may be of the above type when used in connexion with small machines, although, for obvious reasons, magnetic blow-outs are in such case, impracticable.

With large three-phase alternating current motors it is usual to employ oil immersed controllers, in order that the heavy current may be handled without burning and arcing at the contacts.

These oil immersed controllers may be of vertical, but are more often made in horizontal form, as this makes a better arrangement for the connecting cables, while the controller can be so arranged that the tank may be lowered for inspection when necessary. Such controllers can be provided with a handle or hand wheel, while, in the case of very large haulage controllers, signal levers may be adopted, and are placed in a convenient position on the bed of the haulage gear within easy reach of the attendant. In fiery mines it is absolutely necessary to employ oil immersed controllers, in order that there may be no risk of explosion set up by arcing at the contacts.

Controller resistances for haulage work usually take the form of cast-iron grids made up in units, which are often left open, but protecting covers may be provided when required.

The resistances are designed for starting and regulating, and the usual practice is to allow for 50 per cent. speed regulation over periods of ten to fifteen minutes, without undue heating or damage. In special cases the resistances are also designed to give a creeping speed.

Reversing controllers are usually employed independent of whether the hauling gear is of the main and tail or endless rope type, and even for main hauling gears where no tail rope is employed. Although endless rope gears are seldom required to reverse, and main gears are reversed by running the load out on the brake, it may still be necessary at some time or another to reverse the motor quickly, as in the event of a truck getting off the line or a rope jamming. At the same time a reversing costs no more than a non-reversing controller, and, for the above reasons, it is standard practice to employ controllers with a reversing motion, irrespective of the type of gear in connexion with which they are to be used.

A few engineers prefer liquid starting resistances for haulage gears, with the reversing contacts on the apparatus, or embodied in a changeover triple-pole oil-break switch, interlocked with the liquid controller. While this arrangement is cheap for large gears, and has other advantages, it is very seldom employed, and is not standard practice in this country.

The switch panels required in connexion with each haulage gear will usually consist of an automatic switch, fitted in iron case, and, if the power be more than 10 B.H.P., an ammeter must be provided in accordance with Home Office rules.

In some special cases of very large haulage gears, it has been found impracticable to use the standard form of motor, and controller, owing to the severe

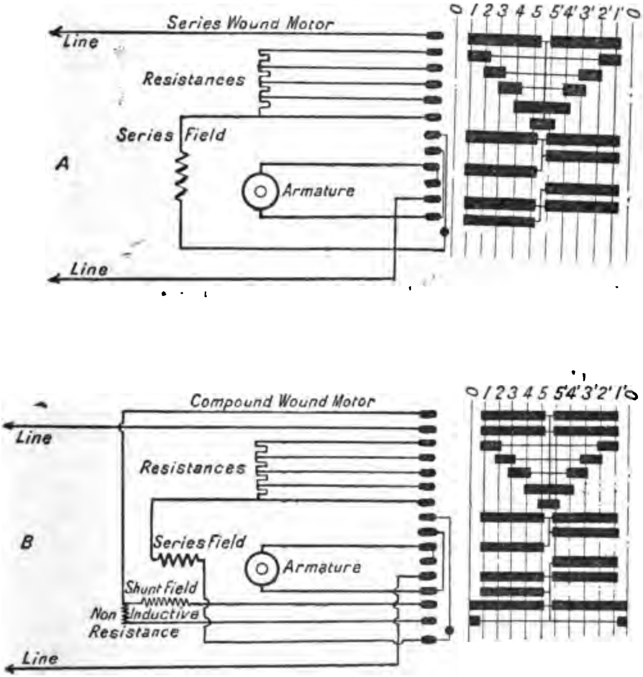

FIG. 24. REVERSING CONTROLLER FOR CONTINUOUS CURRENT MOTORS.

conditions; in such cases haulage gears are arranged on a system very similar to that described for main winding.

In other cases large haulage gears have to be designed to meet special circumstances, and we may find more than one motor operating with series parallel control, in the case of continuous current; or cascade control in the case of three-phase systems.

It may sometimes be necessary, owing to the great distances over which electrical energy has to be transmitted, to wind haulage motors for high tension working, in which case special precautions must be taken in regard to the protection and control of such machines; but the Home Office rules stipulate that no high tension motor of less than 20 H.P. may be used underground.

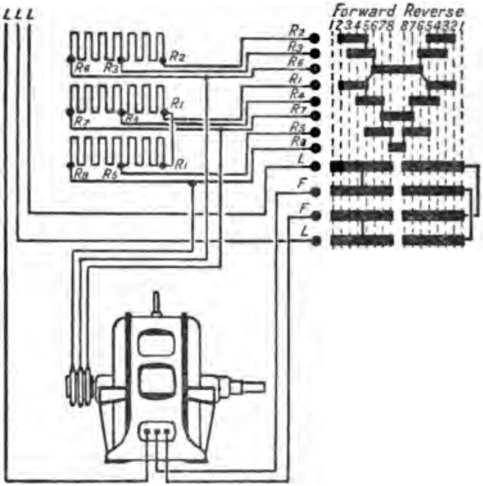

FIG. 25. THREE-PHASE REVERSING CONTROLLER.

Diagrams of connexions for continuous and alternating current controllers are shown in Figs. 24 and 25 respectively. Fig 24, A, shows the connexions for a series-wound, and Fig. 24, *B*, the arrangement for a compound-wound motor. The connexions in Fig. 25 assume the combination of a three-phase motor with a three-phase rotor, but in some cases a two-phase rotor may be used.

In designing haulage gears, makers have to take into account the maximum strains to which they are likely to be subjected, but, in calculating the horsepower required to drive, we take an average of the power required over a complete cycle of operations. The power required will naturally depend upon the load, and the gradient; it will also depend upon the speed and condition of the load, losses in gearing and loads, and upon the type of gear in question. As a rule the quantity of material to be handled is definitely known, and this determines the load. The gradient is also fixed, so that the speed, together with the type of gear, are the only items that remain to be settled. Assuming that all these points have been decided it is a comparatively easy matter to calculate the B.H.P. required.

In regard to speed it may be mentioned that 6 miles per hour is usual for main haulage or main and tail haulage gears, and even greater speeds are sometimes attained in the case of large sets. For endless rope haulage 2–4 miles per hour is usual, although it depends upon weight of rail, and condition of road. If the former be heavy, and the road good, a higher speed can be employed than with light rails and a badly laid road.

Although the power required may be calculated to a nicety from the following formula, a certain amount of reserve should be allowed for, and the maximum not cut too fine. Overloads are bound to occur when one or more tubs are derailed.

In fixing the voltage of haulage motors allowance must also be made for loss in pressure due to transmission, especially if machines are placed at some considerable distance from the generating station. It must be remembered that the speed of the continuous current motor falls practically in proportion to decrease in voltage, although the torque remains constant. With three-phase motors, however, the torque varies directly as the square of the voltage, while the speed of the machine remains constant.

As an example, let us take the case of a main haulage gear, designed to work under the following conditions—

Nett load	12 tons = 26,880 lb.
Nine tubs at 15 cwts. each .	6¾ tons = 15,121 lb.
Length of road . . .	800 yds.
Incline of road . . .	1 in. per foot or $\frac{1}{12}$.
Speed	5 miles per hour.
Haulage rope circumference .	2 in.
Haulage rope weight . .	2¼ lb. per yd.

For single drum working there is only one rope, and the pull due to weight and friction of the rope varies from a maximum to zero as the set is being hauled up. The average pull is obtained by considering the set as being half-way up the road, that is to say, 400 yds. from the drum. The friction of the load is taken as 40 lb. per ton, and that due to the rope as 10 per cent. of its weight.

On this basis it will be easily seen that the total pull on the rope is made up as follows—

Pull due to load 26,880 × $\frac{1}{12}$ = . .	2,240 lb.
Pull due to tubs 15,120 × $\frac{1}{12}$ = . .	1,260 lb.
Pull due to rope 400 × 2¼ × $\frac{1}{12}$ = . .	75 lb.
Friction due to load at 40 lb per ton =	480 lb.
Friction due to tubs at 40 lb. per ton =	270 lb.
Friction due to ropes 400 × 2¼ × $\frac{10}{100}$.	90 lb.
Total pull on rope	4,415 lb.

Then the power required, assuming a speed of 5 miles per hour (440 ft. per minute) = 4,415 × 440 ÷ 33,000 = 59 H.P. Allowing 74 per cent. as overall efficiency of haulage gear, we obtain 80 B.H.P., which will be required for the motor, and, following the usual practice, we should employ a motor of this output, and of one or two hour rating.

The case of the main and tail haulage gear is very similar, but to make matters quite clear we will take another example, of a main and tail haulage gear, designed to work under the following conditions—

Nett load. . . .	15 tons = 33,600 lb.
20 tubs at 20 cwts. each .	20 tons = 44,800 lb.
Length of road . .	1,500 yds.
Incline of road . .	Level.
Speed	6 miles per hour.
Haulage rope circumference	2 in.
Haulage rope weight .	2¼ lb. per yd.
Length of rope . .	1,500 × 2 = 3,000 yds.

With main and tail haulage it is a little difficult to decide what allowance to make for the rope when the load is on varying gradients. Assuming the road to be level, however, there is no difficulty, as it is quite clear there will always be a full quantity of rope lying along the road, both main and tail, or perhaps all tail, and friction must be allowed for accordingly; this is taken as 10 per cent. of the weight of the rope.

Working on this basis we obtain the following values for the pull on the rope due to above load—

Pull due to load (level) . . .	0
Pull due to tubs (level)	0
Friction due to load at 40 lb. per ton .	600 lb.
Friction due to tubs at 40 lb. per ton .	800 lb.
Friction due to ropes, $3,000 \times 2\frac{1}{4} \times \frac{10}{100}$.	865 lb.
Total pull on rope . . .	2,265 lb.

Then the power required, assuming a speed of 6 miles per hour (528 ft. per minute) = 2265 × 528 ÷ 33,000 = 36·3 H.P. Allowing 73 per cent. as overall efficiency of haulage gear, we obtain 50 B.H.P. which will be required for the motor, and in accordance with usual practice we should adopt a motor of two hour rating.

The calculation of endless rope haulages will be very similar to the above, but due allowance must be made for the returning tubs; the pull on the rope, due to gravity, will be equalized. The motor in this case must of course be continuously rated.

In order to arrive at the power required for dealing with any quantity of coal in a given time, by means of main and tail or endless rope haulage gears, the author has obtained permission to reproduce the following tables, prepared by Mr. W. C. Mountain.

Table I gives the power required for main and tail haulage gears, on gradients varying from 2 in., in favour of, to 12 in. in the yard, against the load, and this table may be taken as representing the actual horse-power which will be required under ordinary conditions, with a proper allowance to cover friction. The load in tons includes the weight of tubs, coal, and rope.

TABLE I

H.P. Required for Main and Tail Haulage at 10 Miles per Hour.

Actual Incline in Inches Per Yd.	Virtual Incline in Inches Per Yd.	Load in Tons.										
		5	7·5	10	15	20	25	30	35	40	45	50
–2	0	0	0	0	0	0	0	0	0	0	0	0
–1	1	8·3	12·5	16·6	25	33·2	41·4	50	58	66·4	76	80·8
0	2	16·7	25	33·3	50	66·6	83	100	116	133	150	160
1	3	25	37·7	50	75	100	125	150	175	200	225	250
2	4	33·4	50	67·5	100	134	167	200	233	270	300	334
3	5	41·5	62	83·5	125	167	208	250	290	334	375	416
4	6	50	75	100	150	200	250	300	350	400	450	500
5	7	58·3	87	117	175	234	294	350	408	468	525	588
6	8	66·3	100	133	200	267	333	400	465	532	600	666
7	9	75	112	150	225	300	375	450	520	600	675	750
8	10	83·5	124	166	250	333	420	500	580	664	750	830
9	11	91	137	183	275	366	459	550	640	732	825	918
10	12	99	150	200	300	400	500	600	696	800	900	1000
11	13	108	162	217	325	433	542	650	755	868	975	1080
12	14	116	174	233	350	466	584	700	815	932	1050	1168

TABLE II

H.P. REQUIRED FOR ENDLESS ROPE HAULAGE ON ROAD 1,000 YARDS LONG.

Actual Incline in Inches per Yard.	Virtual Incline in Inches per Yard.	OUTPUT IN LB. PER MINUTE.																
		200	300	400	500	600	700	800	900	1000	1250	1500	1750	2000	2250	2500	2750	3000
−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−1	1	·5	·75	1	1·2	1·5	1·7	2	2·3	2·5	3·1	3·7	4·4	5	5·6	6·2	6·9	7·5
0	2	1	1·5	2	2·5	3	3·5	4	4·6	5	6·3	7·6	8·9	10	11·4	12·7	14	15
1	3	1·5	2·3	3	3·8	4·6	5·3	6	6·8	7·6	9·5	11·4	13·3	15·2	17	19	21	23
2	4	2	3	4	5	6	7	8	9	10	12·6	15	17·6	20	23	26	28	30
3	5	2·5	3·8	5	6·3	7·6	8·9	10	11·4	12·7	15·8	19	22·3	25·4	28	32	35	38
4	6	3	4·5	6	7·6	9	10·6	12	13·7	15·2	19	22·8	26·6	30·4	34	38	42	45
5	7	3·5	5·3	7	8·8	10·5	12·4	14	16	17·7	22	26·5	31	35	40	44	49	53
6	8	4	6	8	10	12	14·2	16	18·2	20·4	25·3	30·4	35	41	45	51	55	60
7	9	4·5	6·8	9	11·4	13·7	16	18	20·5	22·8	28·5	34	40	45	51	57	63	68
8	10	5	7·6	10	12·6	15·2	17·7	20	22·5	25·3	31·7	38	44	51	57	63	69	76
9	11	5·5	8·3	11	14	16·7	19·5	22	25	27·8	34·7	41·7	49	55	62	69	76	83
10	12	6	9	12	15·2	18·2	21·3	24	27·3	30	38	45	53	61	68	76	83	90
11	13	6·5	9·8	13	16·4	19·8	23	26	29·6	33	41	49	57	66	74	82	90	98
12	14	7	10·6	14	17·7	21·3	24·8	28	31·8	35·4	44	53	62	71	80	88	97	106

With main rope haulage it is necessary to take the weight of the main rope only, but in main and tail haulage, the weight of both ropes should be added to that of the coal and tubs on the incoming journey.

It will be noted that the power is reckoned at a speed of 10 miles per hour, but, by taking off the figure on the right, or introducing a decimal point, the table at once gives the horse-power required at a speed of one mile per hour, and if this be multiplied by the actual speed at which the train is running, the actual horse-power necessary will be arrived at.

In calculating horse-powers for main, or main and tail haulage, the length of the road is not taken into account.

Table II. Endless Rope Haulage.—With endless rope haulage, where tubs are attached to the rope at regular intervals, it is sufficient to take the delivery in lb. of coal per minute at the pit bottom, or to whatever point the haulage rope is required to deliver its load, and it will be noted that Table II gives the horse-power required on a road 1,000 yds. long, from a gradient 2 in. to the yd. in favour of, to 12 in. to the yd. against, the load.

In considering the horse-power of an endless rope haulage, it is only necessary to take the average gradient, so that, if the total length of the road be known, and the total rise, this will at once give the gradient, in inches per yd., against which the load has to be drawn.

Assuming the road is more or less than 1,000 yds. long, the horse-power is proportional to its length. For instance, if the road is 500 yds. long, the horse-power required will be one-half that shown in the table; if twice the length, then double.

Mr. W. C. Mountain has made a comparison of the two systems of haulage as regards power required, based upon the above tables, and the following examples will explain the application of the rules, assuming that the work to be done by each haulage is as follows :—

Capacity in 10 hours . . .	600 tons.
Capacity per hour . . .	60 tons.
Capacity per minute . . .	1 ton.
Length of road, 1,760 yds. .	1 mile.
Gradient against load . .	4 in. to the yd.
Weight of each empty tub .	4 cwts.
Weight of coal per tub . .	10 cwts.

The power required for main and tail haulage will therefore be as under :—

Number of trains per hour .	3.
Time allowed for hauling both tubs outbye . . .	8 minutes.
Time allowed for hauling empty tubs inbye . .	8 minutes.
Hitching on full and empty tubs	4 minutes.
Total time per journey in and out	20 minutes.
Number of tubs per journey	40.
Capacity, 10 cwts. each .	400 cwt. or 20 tons.
Weight of tubs, 4 cwt. each	160 cwt. or 8 tons.
Estimated weight of rope .	40 cwt. or 2 tons.
Total weight of train, including coal, tubs and rope .	30 tons.
Speed of haulage . .	1 mile in 8 minutes. or 7½ miles per hour.

From the main and tail haulage Table I it will be seen that, if a load of 30 tons is to be hauled up a gradient of 4 in. to the yd. against the load, at a speed of 10 miles yer hour, 300 H.P. will be required, so that, at the reduced speed of 7½ miles per hour, the horse-power becomes 30 × 7·5 = 225.

For the same duty by the endless rope system, the delivery of coal to the pit bottom being 600 tons in 10 hours, or 60 tons per hour, i.e., 1 ton per minute, the power calculation is as follows :—

Speed of haulage in miles per hour .	2.
Length of road, 1 mile . . .	1,760 yds.
Gradient against the load . .	4 in. per yd.
Coal delivered per hour . . .	60 tons.
Coal delivered per minute . .	1 ton.

Weight of coal per tub	10 cwts.
Number of tubs delivered per minute to pit bottom	2.
Yards travelled per minute by rope on two miles per hour . . .	58·6.
Distance of tubs apart on rope .	29·3 yds.
Number of full tubs on rope . .	60.
Number of empty tubs on rope .	60.

With the endless rope system the full and empty tubs balance each other, and it is therefore only necessary to deal with the actual weight of the coal.

On reference to the horse-power given in the endless rope power Table II, it will be seen that for an output of 2,250 lb. per minute, which is the nearest in the table to 2,240 lb., or 1 ton, on a road 1,000 yds. long, with a gradient of 4 in. to the yard against the load, we shall require 34 H.P.

With the endless rope system the horse-power is increased in accordance with the length of the road, Therefore, the horse-power for a road 1 mile long becomes $34 \times \frac{1760}{1000} = 60$ H.P.

In addition to the foregoing types of haulage gear, we may also mention small portable haulages, for auxiliary work, such as hauling material from the working parts to the main haulage rope. Such sets are usually quite small, and often the power required does not exceed 5 H.P. These haulage gears may be similar to any one of the three already described, though they usually take the form of main haulage with one rope, but in any case the use of such auxiliary plants makes for economy in working, as it dispenses with ponies and only one or two boys will be found necessary for coupling up the tubs, etc., so that considerable saving in working expenses may be effected.

There is also another system of haulage used to a small extent in colliery work, viz., haulage by electric locomotives, but up to the present this method has not found much favour in this country. The endless rope haulage system is preferred, and it must be admitted that it has several advantages over the locomotive, notably as regards efficiency and general convenience.

Dealing first with the question of efficiency, it is obvious that a great deal of power is necessarily wasted in moving the locomotive, which must itself be heavy to give sufficient adhesion. Again, when locomotives are employed more room is required in the roads, despite the fact that designers have made mine-locomotives as compact as possible, and the increased space required is usually sufficient, in itself, to prohibit the adoption of this form of traction or haulage.

There are, however, a few instances where locomotives can be, and are, used with advantage, and these are all operated on the low or medium tension continuous-current system. The Home Office rules are very strict in regard to the use of locomotives, as the following extract will show.

"Electric haulage by locomotives on the trolley wire system, is not permissible in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies. On this system no pressure exceeding the limits of medium pressure may be employed.

"In underground roads, the trolley wires must be placed so that they are at least 7 ft. above the level of the road or track, or elsewhere, if sufficiently guarded, or the pressure must be cut off from the wires, during such hours as the roads are used for travelling on foot, in places where trolley wires are fixed. The hours during which travelling on foot is permitted shall be clearly indicated by notices, and signals, placed in a conspicuous position at the ends of the roads. At other times no one other than a duly authorized person shall be permitted to travel on foot along the road.

"On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

"In order to prevent any other part of the system being earthed (except when the concentric system with earthed outer conductor is used) the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from, or be in connexion with, electric lines otherwise completely insulated from earth.

"If storage battery locomotives are used in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the rules applying to motors in such places shall be also deemed to apply to the boxes containing the cells."

Dismissing storage battery systems for the present as impracticable, it may be stated that the earthed return is the only system commercially possible. This means that one live bare trolley wire is used, and the current returned through the track, which is, of course, in connexion with earth. The alternative to this system would be two trolley wires, and two trolleys, but the complication would put such a system out of court altogether for mining work.

As the earthed return is objectionable the Home Office have stipulated that a separate electric generator shall be used to supply energy to locomotives, so that the earthed return does not represent an earth on the electrical system in general use throughout the mine. This usually means the adoption of an independent motor-generator for supplying the locomotive section, which may be placed down the shaft if possible, or perhaps on the surface, in which case another set of cables will be required down the shaft to supply the locomotive circuit.

Taking everything into consideration it will be admitted that there are several obstacles to overcome before haulage by electric locomotives underground is possible, and it is perhaps not surprising that little headway has been made in connexion with this system.

The electrical equipment of a locomotive would usually consist of two continuous-current motors, each driving one axle through single reduction spur gearing, and controlled by means of a series parallel controller. With the small amount of room available, and the narrow gauge often adopted, it has been rather a problem to design an electric motor to fulfil the required conditions.

The series-parallel system of control, as its name implies, starts up the two motors in series, with resistance in circuit, and, as the controller handle is moved round, the resistance is gradually cut out, leaving the motors running in series at approximately half speed. On further moving the controller handle the motors are coupled in parallel with the resistance again in circuit; this is gradually cut out, step by step, until both motors are running in simple parallel across the line. All these movements are carried out by one hand wheel on the controller, but another handle is usually provided for reversing.

In the case of small locomotives a single series-wound motor may be used with resistance control similar to that adopted for ordinary haulage gears.

The trolley wire is usually suspended by means of insulated hangers carrying an ear, into which the wire is soldered. The current collecting device fitted to the locomotive is known as the trolley, and may be of the ordinary tramway pattern, which, however, requires reversing every time the locomotive changes its direction of running, or, preferably, the bow type, having a roller pressing upwards against the trolley wire, as this form enables the driver to run in either direction without giving any attention to the trolley.

Some electric locomotives are also fitted with a reel of insulated wire to allow of their working in a position beyond the limits of the trolley wire system.

Electric locomotives are, of course, fitted with the usual hand brakes, and, in addition, it is usual to arrange the controller with a rheostatic brake, which is merely an arrangement of connexions, converting the motors into generators and absorbing the energy by means of resistances, when stopping or descending an incline.

One point must not be lost sight of when dealing with this system of haulage, viz., that the locomotive must be heavy enough to give the necessary adhesion to the rails, the weight being a function of the drawbar pull required.

Generally speaking, heavier rails are necessary for locomotive traction than with rope haulages, and, further, the track must be laid with greater care, and must be bonded electrically in order to preserve a continuous electrical circuit for the return current.

CHAPTER VII

ELECTRIC PUMPING

THE driving of a pumping plant by electrical energy is one of the most important, if not the most important, detail in an electrically equipped mine. With pumping plant one of the first essentials is reliability as in many cases a stoppage, even for a short time, might involve serious loss and damage. The type of pump used for mining purposes during the last part of the nineteenth century was that known as the "Cornish" pump, consisting of an old-fashioned beam engine, at the top of the shaft, running perhaps as slowly as four strokes per minute, and operating a pump cylinder underground through the medium of long connecting rods. Needless to say, the arrangement was most uneconomical, but mining engineers had to be content with this plant or face the problem of using steam in the mine. Under the circumstances it is not surprising that electrically driven pumps made so much headway, and it is now generally acknowledged that electricity is far superior to any other power for this particular duty.

Pumping machinery may be divided into two main classes, (*a*) reciprocating pumps; either of the ram or piston type, (*b*) rotary pumps; known as the centrifugal or turbine pattern. Both types are used for mining work and both are suitable for electric driving. Dealing first with reciprocating pumps we find that these are available in several forms, according to the purpose for which they are required, and the local conditions with which they have to comply.

The piston pump may be dismissed without further comment as it is now very seldom used for mining work, and the type known as the "ram" is that always adopted when a reciprocating pump is installed.

The ram pump is single acting and has rams of cast iron, gunmetal, or other special material, working through glands. Such pumps are usually made with three cylinders or barrels side-by-side, and the rams driven by a three-throw crankshaft having cranks at an angle of 120°. This form of construction gives a practically continuous flow of water, and has no dead centres as is the case with a two-cylinder, two-throw pump, which is occasionally used in small capacities.

The ram pump may be of the vertical, or of the horizontal pattern, the type selected for any particular purpose depending, among other things, upon the amount of head room and floor space available.

The speed of the ram pump is necessarily low and some form of speed reduction gear must be introduced when driving from an electric motor. For instance, a three-throw pump having rams, 8 in. in diameter × 12 in. stroke, would run at about 40 r.p.m., thereby delivering about 250 gallons of water per minute, and, assuming a head of about 600 feet, a motor of 65 B.H.P. would probably be required.

A suitable speed for a motor of this size is 750 r.p.m., so that it would be necessary to have a speed reduction of 750 : 40, or 18·75 : 1.

If gearing only be employed this must be of the double reduction type, and the usual practice is to fit a steel pinion on the motor engaging with a cast-iron machine-cut spur wheel on the first motion shaft. The second motion gearing will usually consist of cast-iron pinion and gear wheel, having machine-moulded teeth. Where floor space is no object a rope drive is sometimes employed in place of the first reduction gear.

The turbine or centrifugal pump is so simple in principle that little description is required, but it may be stated that this class of pump is at the same

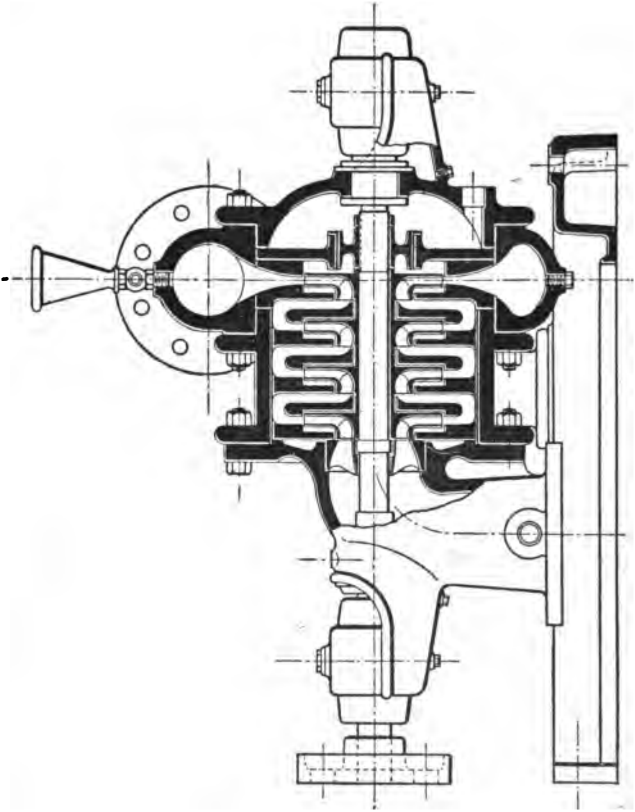

FIG. 26. SECTION THROUGH TURBINE PUMP.

time most difficult from the designer's point of view, when any particular set of conditions has to be fulfilled to the best advantage, and at the highest possi ble efficiency. The plain centrifugal pump, with single impeller, is only suited for small delivery heads. In cases where water is to be delivered against greater heads, the turbine construction must be adopted.

Fig. 26 shows a section through a multi-stage turbine pump, designed by Messrs. Jens Orten Boving, and constructed by Messrs. Willans & Robinson, of Rugby. These pumps may run at almost any speed according to the quantity of water and the head, a speed of 3,000 r.p.m. being not uncommon although about 1,500 r.p.m. is perhaps more usual. It will be seen that turbine pumps are eminently suited for electric driving, in fact it is probable that this type of pump would never have been developed at all had it not been for electric driving.

The motors and pumps are direct-coupled, either through a rigid or, more usually, a flexible coupling, and the motor, together with the pump, are mounted on a common cast-iron bedplate, thereby making a single rigid unit which may be easily transferred and erected where required.

Selection of the best type of pump for any particular duty is a very important consideration, and great care must be exercised. It may be well to consider here the limitations and relative advantages of the two types of pumps above referred to.

The ram pump may be designed for practically any duty required in practice, but it must be remembered that the cost will be more than that of a centrifugal or turbine pump where the conditions are such as to permit the latter being used, and this difference in cost is all the more marked when a pump is required to deal with large quantities of water at a relatively low head. Again, a ram pump requires more room, but, on the other hand, is more easily maintained, and does not require any special technical knowledge on the part of those responsible for its behaviour. In the event of a fault occurring it can be remedied locally without loss of time and inconvenience.

The turbine pump, however, is different, and it is necessary that pumping sets of this character be installed with great care, as any possible alteration in the conditions for which they were originally designed may render the whole plant useless. In this connexion it must be remembered that a centrifugal or turbine pump, designed for any particular head, will not deliver above that head unless the speed be increased, and, while with continuous current motors it is possible to increase the speed by means of shunt resistance, it would be quite impossible to effect this alteration with an alternating current motor. Further, any diminution in the head may increase the quantity of water far in excess of that for which the pump is designed, and this increase is often out of all proportion to the reduction in head, the result being that the motor is seriously overloaded and may be burnt out.

There are, however, turbine pumps on the market so designed that the increase in quantity of water is more or less proportioned to the reduction in head, and with such pumps there would not be this possibility of trouble due to the overloading of the motor. The characteristic performance of such a pump is shown in Fig. 27.

A turbine pump is unsuitable for dealing with a small quantity of water at a relatively large head, and the best conditions are realized when the quantity of water, in gallons per minute, is equal to the head, in feet. If the head, in feet, greatly exceeds the gallons per minute, the efficiency of the turbine pump is low, and the cost, compared with a ram pump, less favourable, so that under these conditions it may be better to adopt a ram pump for such duty.

Electric motors for driving ram pumps will usually be of the protected, or totally enclosed type. On alternating current systems it is usual to adopt wound rotor machines with slip rings for ram pumps, where the torque at starting may be considerable, the machine being used in connexion with a rotor starting resistance in the ordinary way.

If plants are required to run continuously for long periods, it is customary to fit the motor with a short-circuiting and brush lifting device, in order to save wear and tear on the slip rings and brushes. With this device the machine is started up by means of a rotor starting resistance, and, when the set is running

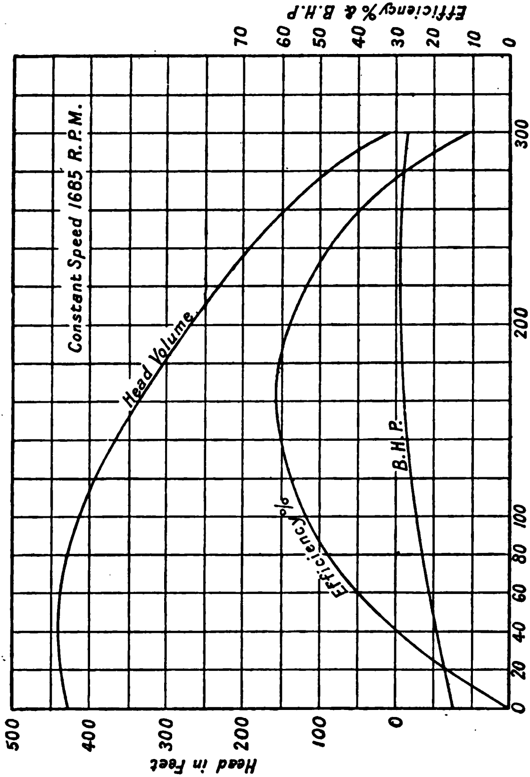

FIG. 27. CHARACTERISTIC CURVE OF TURBINE PUMP.

at full speed the rotor windings are short circuited by means of a lever or knob at the end of the shaft, and the brushes raised off the slip rings. This not only reduces wear and tear, but, if the starting resistance happens to be placed some distance from the motor, there may also be a gain in efficiency, and less slip by reason of the elimination of losses in the rotor connecting cables. It must not be forgotten, however, after shutting down such a motor, to re-set the short circuiting and brush-lifting device, otherwise there may be trouble when it is required to start again.

For alternating-current motors driving turbine pumps it is usual to adopt the short-circuited rotor form of construction, because this is more suitable for high speed working, and the cost is also less than that of wound rotor machines with slip rings. It is possible to adopt short-circuited rotor machines in connexion with turbine pumps because the starting torque is low, and the machines start light, the torque increasing as a function of the speed.

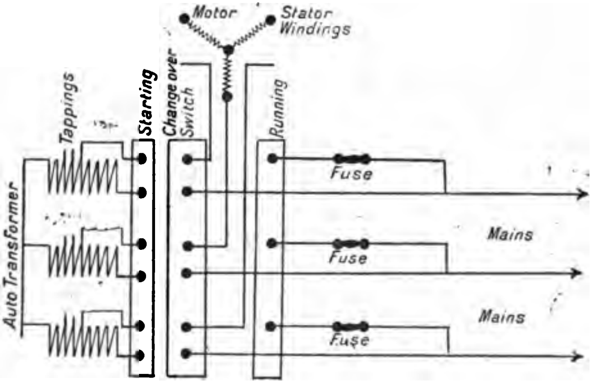

Fig. 28. Auto Transformer Starter Diagram.

The torque during the starting period, with stop valve closed, corresponds approximately to one-third full load torque; then, if the valve is opened, the torque will gradually rise to the normal full load running torque.

This method of starting lends itself admirably to the use of induction motors having short-circuited rotors, used in conjunction with an auto-transformer starter or a star-mesh starter, whilst small sets can be switched directly on the mains, provided the current taken is not sufficient to disturb the supply system to any great extent. The usual arrangement of auto-starting transformers is shown in Fig. 28, and of star-mesh controllers in Fig. 29.

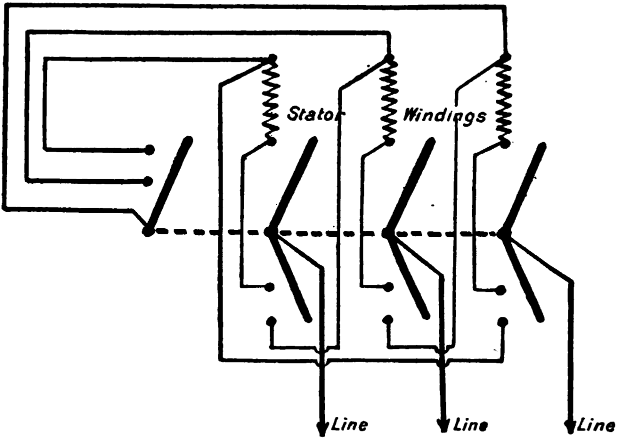

FIG. 29. STAR MESH STARTER.

A good deal of misunderstanding obtains in regard to the starting current and corresponding torque of three-phase induction motors having short-circuited rotors, and it may be as well here to clear up some of these problems.

In order to understand the case aright it is necessary to realize that a motor of this type always exerts its maximum torque at starting, according to the electrical conditions and quite independent of external load. This at first sight may appear incorrect, but when once it is realized that the maximum possible torque is utilized for accelerating the load, and the revolving parts of the motors, it will be seen that the matter at once resolves itself into a question of the time required for acceleration.

If the motor has a heavy load to run up to speed the time required for acceleration will be greater than if the motor had only to accelerate its own mass, but the torque developed in either case will be the same, viz., the maximum possible, depending upon the motor and the electrical conditions.

The whole question of motor torque is bound up with the characteristics of the particular make of motor adopted, but in any case it may be taken that the maximum torque is a function of the terminal voltage and varies directly as the square of the latter.

As a general rule it may be stated that a motor can develop twice full load torque with normal voltage, about full load torque with 70 per cent. of normal voltage, and ½-load torque with 50 per cent. of normal voltage, according to the resistance of the rotor windings.

In the first case the motor would be switched directly on the line, and the current taken would be in the order of four times the normal running current, but assuming an auto-transformer is used in the other cases, with voltage ratios of 70 per cent. and 50 per cent., the current taken from the line will be approximately twice full load, and normal full load, running current respectively.

Auto-transformers are usually provided with a number of tappings, any set of which may be utilized according to the percentage pressure and torque required to suit the conditions of starting. With star-mesh starters the percentage voltage is, of course, fixed, and is given by the expression 100 times $\sqrt{3} = 57$

per cent., so that the machine started up in this manner will develop a little more than half-full load torque. It must be remembered that if star-mesh starters are adopted the motors must be provided with six terminals, as shown in Fig. 29.

With alternating-current motors the speed is limited to a certain extent by the frequency of the supply system. The light load speeds may be found from the formula—

$$\frac{F \times 60}{P.P.} = R.P.M.$$

When F is the frequency in cycles per second and P.P. the number of pairs of poles on the motor. Theoretically P.P. may be any whole number, but there is a limit to the number of pairs of poles for constructional reasons.

Generally speaking, it is preferable to run alternating current motors at as high a speed as convenient, in order to keep down expense, and at the same time obtain a better machine. For any particular horse-power required it must be remembered that the slower the speed the lower will be the efficiency and also the power factor.

The speed given by the above formula is that at which the motor will run without load. The full load speed will be slightly less than this, the difference between the speeds at light load and full load being known technically as "slip." This "slip" is usually expressed as a percentage, and its value may be anything up to 8 per cent. for small motors of 1 B.H.P., to 5 per cent. in motors of 10 B.H.P. With still larger machines the slip may be only 3 per cent. for, say, 50–100 H.P. and even lower in the case of very large powers.

The speed of alternating current motors is of course independent of the voltage except in the special case referred to in detail in Chapter IX. When continuous-current motors are employed the machines can be designed for any speed desired. Then machines are usually shunt wound for both plunger and also turbine pumps, but may be occasionally compound-wound in the former case, where it is necessary to start up against a heavy load such as a long column of water in the delivery pipe.

The horse-power required to drive a pump of any description is given by the formula—

$$HP = \frac{W \times H}{33{,}000}$$

Where W equals the weight of water raised per minute, and H the total head in feet.

This expression gives the theoretical or water horse-power and the result must be increased to allow for the efficiency of the pump. For instance, if the pump efficiency is 70 per cent., the water horse-power must be increased in the proportion of 70 : 100.

In dealing with all pumping problems we constantly meet the expression "total head" which includes :—

(*a*) The head due to suction (i.e., height from suction level to pump).

(*b*) The head due to delivery (i.e., height from pump to delivery level).

(*c*) The head due to pipe friction.

All heights must of course be reckoned vertically. The head due to suction is limited, and, with the barometer at 30 in. cannot be more than 33 ft. theoretically. In practice it is necessarily less, because we cannot produce anything like a perfect vacuum with ordinary pumping machinery, and with pipe lines and joints as usually constructed. It will be found that 24 ft. suction, including the head due to friction in the suction pipe, is all that can be expected, and it may often be found impossible to obtain as much as 24 ft. suction.

With short suction and delivery pipes the increase in head due to friction is negligible, and may be disregarded, but with long pipe lines it becomes an important factor and has to be reckoned with. The equivalent increase in head may be calculated from well known formulæ when the velocity of the water in the pipes and their internal diameter are known. This calculation, however, is rather laborious, and the following table has been prepared in order that the desired result may be obtained more easily. In using this table we only require to know the quantity of water delivered, in gallons per hour, together with the internal diameter of the pipes proposed. From this table it will also be possible to determine the

APPROX. FRICTION IN FEET HEAD PER YARD OF PIPE.

Galls. per hour.	DIAMETER OF PIPE IN INCHES.									
	2	3	4	5	6	7	8	9	10	12
600	·0133	·0017	—	—	—	—	—	—	—	—
1,200	·0516	·0070	·0016	—	—	—	—	—	—	—
1,800	·1158	·0158	·0038	·0012	—	—	—	—	—	—
2,400	·2060	·0277	·0066	·0021	—	—	—	—	—	—
3,000	—	·0426	·0105	·0035	·0013	—	—	—	—	—
3,600	—	·0609	·0145	·0049	·0020	—	—	—	—	—
4,800	—	·1089	·0259	·0084	·0035	·0016	—	—	—	—
6,000	—	·1695	·0405	·0134	·0056	·0026	·0013	—	—	—
7,500	—	·2650	·0625	·0215	·0084	·0039	·0019	·0011	—	—
9,000	—	—	·0905	·0299	·0129	·0055	·0029	·0016	·0010	—
10,500	—	—	·1260	·0450	·0165	·0078	·0039	·0022	·0013	—
12,000	—	—	·1650	·0529	·0216	·0099	·0055	·0029	·0016	—
15,000	—	—	·2500	·0835	·0344	·0155	·0079	·0045	·0027	·0010
18,000	—	—	—	·1194	·0486	·0230	·0116	·0064	·0039	·0015
21,000	—	—	—	·1622	·0650	·0310	·0156	·0085	·0055	·0021
24,000	—	—	—	·2109	·0856	·0395	·0204	·0115	·0068	·0029
27,000	—	—	—	·2269	·1075	·0496	·0256	·0144	·0085	·0034
30,000	—	—	—	—	·1333	·0622	·0314	·0174	·0105	·0042
36,000	—	—	—	—	·1915	·0892	·0455	·0251	·0148	·0065
42,000	—	—	—	—	·2598	·1210	·0616	·0345	·0204	·0084
48,000	—	—	—	—	—	·1569	·0814	·0446	·0266	·0116
54,000	—	—	—	—	—	·1985	·1019	·0564	·0335	·0136
60,000	—	—	—	—	—	·2460	·1266	·0710	·0426	·0165
75,000	—	—	—	—	—	—	·1959	·1110	·0655	·0265
90,000	—	—	—	—	—	—	·2836	·1560	·1055	·0377
105,000	—	—	—	—	—	—	—	·2150	·1353	·0550
120,000	—	—	—	—	—	—	—	·2780	·1666	·0664
150,000	—	—	—	—	—	—	—	—	·2592	·1043

best size of pipe to deal with any given quantity of water. In addition to the increase of head by reason of pipe friction, it must not be forgotten that bends, change of direction, or change in the size of pipe, may occasion some loss which must be allowed for.

Another class of pump known as a "sinking pump" is used when it is required to unwater a mine that has become flooded. This sinking pump is not fixed but is suspended from chains in the shaft, and is lowered a few feet at a time, as the water is pumped out of the mine.

A sinking pump may be of the plunger or the turbine type.

When a turbine type of sinking pump is employed this is always of the vertical shaft pattern, the motor being direct-coupled above the pump, through a flexible coupling. This form of coupling is absolutely necessary with a vertical shaft pump and motor, in order to ensure that the weights of the parts are properly taken by their respective bearings. The pump bearings must be designed to take not only the weight of the impeller, but also any thrust that may arise, while the motor bearings carry the weight of the armature or rotor only.

Motors for sinking pumps of any description should preferably be of the totally-enclosed type or should at least be provided with an efficient shield against water and dirt dropping down from above.

If the motors are continuous current, they should be shunt or compound wound, while for three-phase work it is preferable to use machines with permanently short-circuited rotors. This is to save the necessity of bringing an extra three-core cable up the shaft from the slip rings to the rotor starting resistance.

Great care must be taken, in laying out a sinking pump installation, to see that the motor and pump are well up to the duty required and it is a great mistake to cut things fine for this class of work. If there is a considerable run of cable from the generating station to the pump, due allowance must be made for the pressure drop in this cable. With a continuous current system the loss in pressure may cause the motor to run slow, and it will then be unable to pump the required quantity of water, while if the pump happens to be of the turbine type it may be impossible to get any delivery at all if the speed of the motor is much less than that for which the pump is designed.

With an alternating current system, the loss in pressure will seriously affect the starting torque (which varies as the square of the pressure at the motor terminals) and the Author has known of cases where great trouble was experienced at starting due to this cause.

It is not always commercially practicable to so increase the size of the connecting cable as to limit the pressure drop to say 5 per cent., but it is always possible to calculate the actual voltage delivered at the motor terminals and design the machine for this pressure. This is a point that should have attention in all cases when motors are placed at a great distance from the power station, especially if continuous-current motors are used for driving turbine pumps, as these are very sensitive to comparatively small variations in speed.

It must not be forgotten that all centrifugal or turbine pumps require priming, that is to say the pump casing and suction pipe must be flooded with water before the pump will act. This priming may be done from the main delivery pipe in some cases, or the pump casing may be filled from any water supply system, a special charging or priming cock being provided on the casing for this purpose. It is needless to state that a non-return valve must be provided at the foot of the suction pipe to retain the water.

The installation of a sinking pump for unwatering a mine is an expensive matter, especially if the plant has no further use after completing the duty for which it was purchased. For this reason some makers now design plants which can be used as permanent pumps at the bottom of the shaft after sinking operations are completed. As already mentioned, in the case of a turbine pump it is only possible to secure the best efficiency when the plant is working under the exact conditions for which it has been designed, and, consequently, any great alteration in these conditions means considerable loss in efficiency.

Now it is evident that in a sinking pump installation the conditions vary very much, inasmuch as the head may be only a few feet when commencing to unwater the mine, and may increase to several hundred feet at the finish of the operation.

The pump must obviously be designed for the maximum load, which only occurs when the plant is pumping from the very bottom of the pit. With a plunger pump the motor will run continuously at full speed, and the horse-power absorbed will adjust itself more or less to the work done. With a turbine pump the case is very different, and it is necessary to vary the speed of the motor in order that the pump shall deliver the required quantity at the various heads, or, alternatively, a throttle valve must be used on the delivery pipe which is equal to an artificial head. Speed regulation is impossible with polyphase motors of the short-circuited rotor type, and is difficult to carry out or is inefficient with other types of motor. Under the circumstances we usually regulate by the throttle valve on the delivery pipe. This arrangement is also inefficient as the motor is practically working at full load when the pump is delivering at a few feet head. For very large installations, where efficiency is of first importance, multistage turbine pumps may be used, one stage only being employed say for the first 50 ft., the second stage, third stage, etc., being added as the pump gets deeper and deeper in the shaft. This plan maintains a high efficiency throughout the complete operation of unwatering a mine.

A sinking pump must of course be provided with a winch, and wire rope, or chain, for supporting the complete plant from the top of the shaft. The connecting cables must be of rubber in order to be flexible, the two or three conductors being formed into one cable, and suitably armoured and protected from corrosion. A suitable cable drum must be arranged for at the top of the shaft to pay out the cable as required.

In mining work it is sometimes necessary to provide small dip pumps and portable pumps for use in the workings. These are often built up on a four-wheel truck to facilitate transport. These pumps do not call for special comment. They may be of the plunger or turbine pattern, driven by continuous current or polyphase motors. If flexible connecting cables are used for portable pumps, the reader is referred to the remarks in Chapter V in reference to these cables.

CHAPTER VIII

ELECTRIC COAL CUTTING AND DRILLING

ELECTRIC Coal Cutting is yet another example of the machine displacing hand labour, although in this case the mining engineer usually regards it as a device for not only cheapening the cost of getting coal, but also enabling him to obtain a greater quantity from a given working, than would be possible with hand labour. Coal cutters therefore really increase the capacity of a mine provided the haulage plants are capable of dealing with the quantity required and the winding engines are designed to bring the desired amount to the surface. If one or other of these agencies, however, is not sufficient for its work, then the quantity of coal brought up must depend upon the slowest, just as the strength of a chain is that of its weakest link.

In actual practice it is found that, with a given working face, three times the output may be obtained if coal-cutting machines are employed instead of hand labour.

In addition to increasing the capacity of the mine, and cheapening its working, there are other considerations in favour of coal-cutting machinery which will appeal to mining engineers, and machine working is gradually taking the place of hand labour.

Before passing to the electrical aspect, it will be as well to mention the three distinct types of coal cutters used, according to local requirements. These are respectively known as "The Chain," "The Bar," and the "Disc Type," each having its own peculiar advantage in practice, although of course each particular maker has special claims for his own pattern of machine.

The design of the electric motor for driving coal cutters has presented many problems, owing to the severe conditions under which it is required to work, and to the necessity for restricting its dimensions to a degree which renders it difficult to obtain the required power.

The standard electric motor will not do at all, and the coal-cutter motor (like the traction motor) is a speciality, designed for its own particular purpose. It goes without saying that the machine must be very well built; the shaft must be extra strong, and the magnet coils rigidly fixed to the pole pieces, as the vibration is at times excessive. The motor is of course totally enclosed, and must be designed to work under the required conditions, without an excessive temperature rise.

The starting gear, too, must be of strong and robust design, liberally rated for its duty, and suitable for rough usage. A starter, or controller of the drum type is best, having all parts enclosed in a strong iron case, and operated by an external handle or hand wheel.

All early coal-cutter motors were of the continuous-current type, and, as may be expected, trouble was experienced in connexion with the commutator and brush gear. Many coal-cutting machines have been made lately with three-phase motors having permanently short-circuited rotors, and such machines, when a three-phase supply is available are distinctly advantageous. The starting gear for these three-phase motors is of the simplest possible description, consisting of a plain triple-pole switch in a cast-iron case, by means of which the rotor is switched direct on to the circuit without the use of any resistances, the current taken from the mains under these conditions being equal to about three times the full load running current of the motor. This mode of starting is perhaps more suitable for the bar than for the disc and chain types of cutter, because the former starts comparatively light, while the latter require a considerable starting torque. In a three-phase motor it is only possible to obtain a high starting torque by employing a high resistance rotor, or, what comes to the same thing, a resistance in the rotor circuit. This, therefore, means that for disc and chain machines three-phase motors with wound rotors must be employed in conjunction with rotor starting resistances.

With continuous current motors some coal-cutter makers use series-wound machines which have the advantage of a high starting torque and good overload capacity which are very useful since the machine may jam or meet some unexpected obstruction in cutting. The speed of the series motor of course falls considerably in the event of an overload, but this is perhaps an advantage, because the total horsepower used is consequently less than if the speed remained constant, and therefore the emergency demand from the mains is also less.

Other makers recommend shunt motors, which have the advantage of maintaining an approximately constant speed, even when running quite light, under which circumstances the series motor is at a disadvantage because its tendency is to race.

Compound-wound motors are also used, and it would seem that they are the most suitable, as they possess the characteristics of both shunt and series wound machines.

Motors for bar coal-cutters might be shunt wound, or have a light series winding, whilst those for disc and chain machines would be compound-wound with a heavy series winding, or they might be described as series-wound machines with a light additional shunt winding, sufficient to prevent racing on light load.

As the electric coal cutter is essentially a portable machine, it cannot be permanently connected to the supply system. This means that a length of flexible cable is required, of sufficient length to follow the machine in its work, one end being attached to the machine and the other terminating in a suitable connexion box, fixed, and permanently connected to the main supply system, at the nearest point to that where the coal cutter is at work.

In accordance with Home Office regulations, which state that motors of coal cutters and other portable machines shall not be used at a pressure higher than medium pressure, it follows that the voltage never exceeds 650. The trailing cables are specified to be specially flexible, heavily insulated, and protected with either galvanized steel rim armouring, extra stout binding, hose pipe or other effective covering. It is also imperative that these trailing cables be examined at least once in every shift.

At the point where the connexion box is fixed, it is also necessary to provide a switch, capable of entirely interrupting the supply to the terminal or connecting box, and consequently, to the coal-cutter motor.

The power required usually varies between 15 H.P. and 20 H.P., although much depends upon the make and type of machine and the duty put upon it.

In this section we also include electric drills for colliery work, although it must be admitted that the field for this type of drill is somewhat limited. The compressed air drill has been used almost exclusively for colliery work until recently, in fact even now compressed air drills are still desirable for certain operations.

Electric drills for colliery work are of two distinct types, viz.; "rotary" and the "percussive," the latter being expressly suitable for rock, and very hard material, where a rotary drill would not make any impression.

The former usually consists of an ordinary motor, either of the continuous or three-phase alternating current type, driving the drill through the medium of gearing or a flexible shaft. In some cases the drilling machine is mounted on a four-wheeled truck, but in other situations it may be more suitable to attach the drill to a rigid stand, fixed in position by means of stays, or wedged between the floor and roof of the workings, the power being communicated from the motor by means of a flexible shaft, or through universal joints.

These machines are fitted with steel drills for dealing with soft material, and diamond drills for medium rocks. When hard rocks have to be negotiated the percussive drill is employed. This type is reciprocating and, consequently, ill adapted to a rotary motor drive.

In one form electricity is made to act electromagnetically upon a steel plunger, no motor being employed. Two coils or solenoids are provided in the drill casing, and energized alternately by current from a special generator, causing the steel plunger to oscillate between them, with a slight rotary movement due to rifling of the plunger. This drill makes between 300 and 400 strokes per minute, and as several such machines may be used in conjunction with one special generator, the system becomes extremely flexible.

Other forms of percussive drills can neither be termed electric nor compressed air drills, but are essentially a combination of the two, an electrically driven air compressor being used whilst the drill proper is of a simple pneumatic type.

Despite the great advances made in connexion with electric coal drills in the past few years, there are those who still favour the compressed air pattern, but it remains that in most of these cases the air compressors are electrically-driven if electrical energy is available, for economical reasons.

With regard to the supply of electricity for drills, there is not much to be said, except that it must be of low or medium tension, and that the general rules relating to the use of portable machines in mines must be observed.

Flexible cables are of course employed to a great extent and the same rules apply as mentioned above in connexion with electric coal cutters.

CHAPTER IX

ELECTRIC VENTILATING

We now come to another branch of mining work to which electricity has been applied with most favourable results, namely, ventilation.

General Rule No. 1 of the Coal Mines Act, requires that an adequate amount of ventilation shall be constantly produced in every mine, to dilute, and render harmless, noxious gases, to such an extent that the working places of the shafts, lures, stables and workings of the mine, and the travelling roads to and from these working places, shall be in a fit state for working and passing therein.

In earlier days it was customary to obtain the necessary ventilation by means of a furnace placed at the greatest possible depth adjacent to the upcast shaft. This method worked well when the workings were short, and consequently offered small resistance to the passage of the gases; but in mines having long air courses, with a correspondingly high resistance, the pressure obtained by means of the furnace is insufficient to induce the necessary change of air.

In these cases mechanical ventilation must be employed, and the first step was to instal large fans, usually direct coupled to steam engines, and running at a slow speed. These, it must be admitted, were reliable, but very bulky and inefficient, so that it is not surprising that their place is being taken by smaller, high speed, electrically-driven fans.

The fans usually adopted are of the centrifugal type, which has now been brought to a high pitch of perfection. They are either direct-coupled to the motor shaft, or driven by means of belt or ropes. The fan consists of a runner, or impeller, enclosed in a spiral casing very similar to that of a centrifugal pump, and, if the motor speed is suitable, this runner is often mounted direct on the motor shaft, the motor itself being placed close up against the spiral casing. This arrangement has the advantage of being cheap and compact, while there are only the two motor bearings to look after and lubricate. A combination bedplate is arranged to carry both motor and fan casing.

It must be understood that the diameter, width, and speed of the fan, are determined by the quantity of air, and pressure required for ventilating any particular mine. The electric motor driving the fan must then be designed to suit these conditions. In many cases it happens that a fan, running at a comparatively slow speed, is necessary to fulfil certain conditions, in which case it may be preferable to instal a belt or rope drive from a high speed motor, instead of a direct drive from a large, and consequently more expensive slow speed motor.

We need not concern ourselves here with the design, speed, or diameter of fans for any particular service, all of which details may safely be left to the fan maker; but it will be useful to determine the horse-power required to drive a fan dealing with a given quantity of air at a certain pressure.

Let $V =$ the capacity of fan in cubic feet per minute.

Let $P =$ the pressure, usually measured in inches (water gauge).

Then the theoretical horse-power will be given by the expression $\text{H.P.} = V \times P \times 5{\cdot}2 \div 33{,}000$.

The constant, 5·2, is the weight of one square foot of water, one inch deep, which is the equivalent of 1 in. (water gauge). The actual horse-power required to drive the fan must, of course, be increased to cover the loss in conversion and the efficiency of a well designed fan will be in the neighbourhood of 70 per cent.

If continuous-current motors are adopted it is usual to provide shunt or compound-wound machines, and it is advisable to instal a shunt regulating resistance in order that the speed may be adjusted to suit the exact conditions.

When three-phase motors are employed, these may with advantage be of the short-circuited rotor pattern, in order to save the wear and tear of slip rings. In such case the motors would start up light in conjunction with an auto-transformer starter.

In installing fans one point must not be lost sight of, namely, the requirements of General Rule No. 3 of the Act, in which it is stated that, when a mechanical contrivance for ventilation is introduced into any mine, it shall be in such a position and placed under such conditions, as will tend to ensure its being uninjured by an explosion.

It frequently happens in connexion with mine fans, that some method of reducing the capacity is required during holidays and week ends, and this may be easily achieved by reducing the speed of the fan and motor. With continuous current motors the necessary speed regulation may be obtained by means of resistance in series with the armature, or, if a more economical method is preferred, by regulation of the shunt field winding, although the latter method means that a larger and consequently more expensive motor will be required.

With three-phase motors having wound rotors and slip rings, speed regulation may be obtained by means of rotor resistance, which is analogous to the continuous-current motor regulated by resistance in series with the armature. With three-phase motors having short-circuited rotors, regulation in speed may be obtained by varying the pressure at the terminals. This may be effected by means of a controller and resistance, or by an auto-transformer or choking coil, the latter method having the advantage of a higher efficiency.

It must not be assumed that this method of speed regulation can be adopted for any three-phase motor of the short-circuited rotor type, operating on any load. We have already seen that the maximum torque produced by any three-phase motor varies in proportion to the square of the voltage; in order therefore to secure stable speed regulation it is necessary that the torque required to drive should vary in proportion to some higher power of the speed. In the case of the fan, the torque required to drive varies as the cube of the speed; hence the necessary condition is fulfilled for this particular purpose, and the method may be adopted for fan driving.

There are other methods of speed regulation in connexion with three-phase motors sometimes used when these machines are required to drive fans. The most important is that known as the "cascade system" and is analogous to the well known series-parallel control for continuous current machines. Two similar motors are used, and normally run in parallel at full speed. When connected in cascade, the rotor windings of one motor must be connected to the starter of the other.

Under these conditions the first motor is acting partly as a motor and partly as a transformer. One half of the energy received from the line is converted into mechanical energy by the first motor, which runs at half speed, and the other half is transmitted electrically to the second motor, at half the frequency of the initial supply. Both motors will therefore run at half speed, and develop nearly full torque, the energy required from the line being the same as would be necessary to drive one motor alone.

The method of speed control is very efficient, but there is no intermediate regulation between full and half speed. But in cases where this amount of regulation is desirable, and the complication of two motors is not objected to, the system lends itself admirably to the purpose of driving mine fans.

Another method of varying the speed of three-phase motors is by changing the number of poles. This also is an efficient method, but no intermediate steps between full speed and half speed can be obtained.

In actual practice the number of poles is changed by paralleling adjacent poles. For instance, assuming an eight-pole motor, running at a speed of 750 revolutions per minute (synchronous speed). On a 50-cycle circuit the poles will be arranged in the order, N.S., N.S., N.S., N.S. By paralleling adjacent poles we now obtain, N.N., S.S., N.N., S.S., which would constitute a four-pole motor, having broad poles, and running at a speed of 1,500 revolutions per minute.

Special switch gear is necessary to effect the change in the number of poles, and the extra complication is somewhat expensive, so that the method is rarely employed in actual practice; but in cases where it is applicable, it has the advantage of being efficient, and, further, only one motor is required, as against two for the cascade system of control.

When fans are direct coupled to three-phase motors, only certain speeds are possible, depending upon the frequency of the supply, and the number of poles on the motor, full particulars of which are given in Chapter VII, dealing with electrically driven pumps, and to which the reader is referred.

CHAPTER X

ELECTRIC WINDING

WITHIN the last ten years there has been a great deal of discussion as to whether main winding by means of electric power is commercially practicable. Colliery managers who have adopted electric power for hauling, pumping, ventilating, and coal cutting, have hesitated to instal electric winding engines for main winding.

On the Continent progress has been more rapid, and, consequently, there are a large number of main winding engines abroad, in regular service, demonstrating that electric power can be used with economy and real success for this class of work.

The only competitor is the steam winding engine, which has now been in use for so many years, and may still be seen in most of our British collieries. But one by one we hear of electric winding engines being installed, and there is no doubt that, as the merits of the electric winder become more fully recognized, it will be adopted for all our important collieries.

A great deal has been written on this subject; but mostly on the question of electric *versus* steam winding, and it is not intended to discuss the relative merits of the two systems here. Suffice it that it has been proved that electric winding is decidedly more economical for all important collieries, dealing with a good class of coals; but it is questionable whether it would pay to put down an expensive plant to deal with coal which has only a small market value. In such cases actual economy in working is less important, and one can afford to use such coal uneconomically for raising steam.

The subject of electric winding is most interesting because of the peculiar nature of the problems involved. It will be seen that the principal difficulty lies in the widely fluctuating load, which may vary from zero to 2,000 H.P. or more, in a few seconds according to the weight, speed of winding, and acceleration.

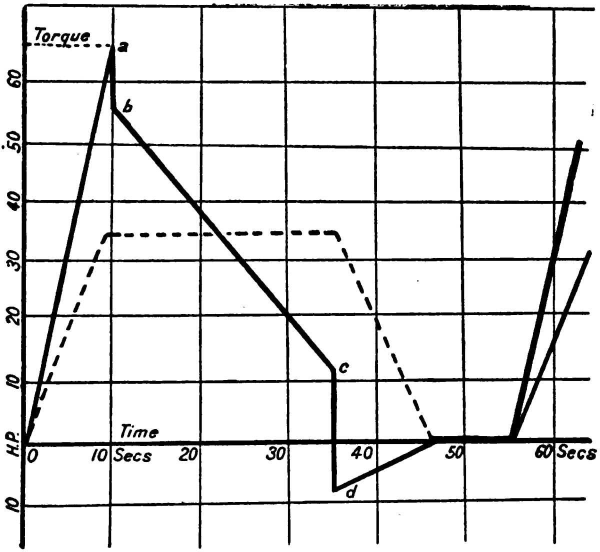

FIG. 30. WINDING ENGINE LOAD CURVE.

The curve, Fig. 30, conveys a good idea of the load variation in actual practice, and it will be seen that the conditions are not ideal from an electrical standpoint. In order to take care of the widely fluctuating load, and preserve as nearly as possible a steady load on the generating plant, all main winding systems of any size include what is known as an "equalizer," or a flywheel storage system as described later on.

Let us first consider the case of a winding plant where the power required is comparatively small and where a simple motor and controller can be adopted without a load equalizer. The leading particulars are usually obtained in the following form :—

Depth of shaft	400 feet
Total amount of coal per day . .	260 tons.
No. of working hours per day . .	8 hours.

There are obviously several ways in which the above conditions may be complied with ; but for the purposes of our calculation, we will assume that it has been decided to allow 55 seconds for each wind, that is, say, 65 winds per hour. It will thus be necessary to raise 10 cwt. of coal at each wind, in order to bring up the 260 tons in a working day of eight hours.

These particulars, together with the weight of the cage, hutches, and rope, may then be put down as follows :—

ASCENDING LOAD AT COMMENCEMENT OF WIND.

Weight of rope	10 cwt.
Weight of cage and hutches . . .	15 cwt.
Weight of coal	10 cwt.
Total	35 cwt.

DESCENDING LOAD AT COMMENCEMENT OF WIND.

Weight of rope	0
Weight of cage and hutches . . .	15 cwt.
Total	15 cwt.

It will next be necessary to consider the speed of winding and acceleration of the load. Bearing in mind that this is a small winder, and that we are only employing a simple motor and controller, without any equalizer or flywheel storage, it will be as well to allow as long a period as possible for acceleration, in order to prevent any wide variations of load on the generating plant.

Assuming that ten seconds will be required at the end of each wind for loading and unloading, this will leave forty-five seconds for the actual wind, which corresponds to an average winding speed of 535 ft. per minute.

We therefore set these particulars down as follows :—

No. of winds per hour . .	65.
Time required for each wind .	55 seconds.
Time required for banking .	10 seconds.
Time required for actual wind	45 seconds.
Average winding speed . .	535 ft. per minute.

The next thing to decide is how to proportion the time for acceleration, full speed period, and retardation, which, together, make up forty-five seconds. Bearing in mind that we wish to prevent any wide variations in load on the generating plant, it will suffice to allow ten seconds, twenty-five seconds, and ten seconds respectively for the three operations named above. From these we are now able to calculate the actual acceleration, the maximum winding speed, and the horse-power required at all periods throughout the wind.

The calculation necessary to arrive at the horse-power required at various points during the wind is somewhat complicated by the rope, which is all against the motor at the commencement of the wind; but which is gradually passing from the ascending load over to the descending load, and may in some instances actually assist the motor towards the end of the wind.

The best way to deal with the matter is by plotting a curve, and we will now calculate the horse-power required at four points of the curve. The maximum horse-power occurs at the end of the acceleration period, and is composed of the horse-power required for acceleration, plus that required for lifting the load at the maximum winding speed, which we have yet to determine. If the acceleration and retardation are constant, it is evident that the average speed of winding during these periods is equal to half the maximum winding speed, and that the distance traversed by the load will be equal to half the maximum speed multiplied by the time.

From this we can find the maximum winding speed.

$$\frac{\text{Total length of wind.}}{\text{Half acceleration period} + \text{full speed period} + \text{half retardation period.}}$$

In our case this will be as follows:—

$\frac{400 \text{ ft.}}{5 + 25 + 5}$ which equals 11·4 ft. per second, or 690 ft. per minute.

As the distance traversed during acceleration is equal to half 690 ft. per minute, multiplied by ten seconds, we find that 57·5 ft. of rope will have been transferred from one side of the system to the other at the point where maximum horse-power occurs, that is, at the end of the acceleration period.

A weight corresponding to this length of rope must therefore be subtracted from one side and added to the other.

If 400 ft. of rope weigh 10 cwt., 57·5 ft. equals 1·44 cwt., which leaves 8·56 cwt. on the side with the load.

The loads to be dealt with at this point will be as follows:—

	Ascending.	Descending.
Weight of rope . .	8·56 cwt.	1·44 cwt.
Weight of cages and hutch	15 cwt.	15 cwt.
Weight of coal . .	10 cwt.	0 cwt.
Totals	33·56 cwt.	16·44 cwt.

Difference in loads 17·12 cwt. = 1,920 lb. approximately.

$$\text{H.P. required} = \frac{1{,}920 \text{ lb.} \times 690 \text{ ft. per min.}}{33{,}000 \text{ ft.-lb. per min.}}$$
$$= 40 \text{ H.P. approximately.}$$

We now want to calculate the horse-power required for acceleration. Since we obtain a speed of 690 ft. per minute in ten seconds, the acceleration is 690 ÷ 10 = 69 ft. per minute per second, or say 1·15 ft. per second per second.

Now from elementary principles of mechanics we know that a force of 1 lb., acting on a mass of 1 lb., will produce an acceleration of approximately 32 ft. per second per second, so that in our case the pull on the rope, due to acceleration, will be: Equal to the total mass of the two cages, the whole of the rope, plus the coal, multiplied by the acceleration of the load, and divided by the acceleration due to gravity.

$$\text{That is, } \frac{5{,}600 \text{ lb.} \times 1{\cdot}15}{32} = 200 \text{ lb.}$$

The horse-power, at full speed, required for acceleration will be:—

$$\frac{200 \text{ lb.} \times 690 \text{ ft. per min.}}{33{,}000 \text{ ft.-lb. per min.}} = 4{\cdot}2 \text{ H.P.}$$

The above figures represent theoretical results, and the horse-power due to gravity must be increased to allow for friction, while the horse-power due to acceleration must be increased to allow for the inertia of the drums and gears of the winding engine, as well as the pit head sheaves, and a certain amount of extra rope. In an important case it would be necessary to calculate these items separately, and add them to the total; but in this case the amounts involved are small and we can make an allowance for same.

In this case we can assume an efficiency of 70 per cent. for the winding engine, which will cover the friction of the rope and guides, while we will increase the horse-power due to acceleration by 40 per cent. to cover the inertia of the parts not taken into account in the foregoing calculation.

This makes horse-power due to gravity = approximately 37 H.P., and the horse-power due to acceleration = 6 H.P.

The total of these results gives us the first point (*a*) on the curve (Fig. 30), while the second point (*b*) is that corresponding to the horse-power due to gravity only.

The next point to calculate is the horse power at the end of the full speed period, and to obtain this we must first ascertain the load on each side of the system. Proceeding as before, we obtain the loads to be dealt with at this point as follows :—

	Ascending.	Descending.
Weight of rope . .	1·44 cwt.	8·56 cwt.
Weight of cages and hutches	15 cwt.	15 cwt.
Weight of coal . .	10 cwt.	0 cwt.
Totals	26·44 cwt.	23·56 cwt.

Difference in loads, 2·88 cwt. = 322 lb. approximately.

$$\text{H.P. required} = \frac{322 \text{ lb.} \times 690 \text{ ft. per min.}}{33{,}000 \text{ ft.-lb. per min.}}$$

$$= 6{\cdot}7 \text{ H.P. approximately.}$$

Allowing 60 per cent. efficiency at this point, we obtain 11 H.P.

This, then, is the third point (*c*) on our curve.

After this, power is cut off, the brakes are applied, and the retardation period begins. The horse-power must now be considered as having a negative value.

The horse-power at this point is entirely due to the inertia of the load, together with the drums and gears, pit head sheaves, etc., and may be calculated in exactly the same manner as given above for acceleration. In our particular case, however, we have taken the same length of time for acceleration, as for retardation, and the horse-power will therefore be the same, namely, 6 H.P., including the inertia of the drums, gears, pit head sheaves, etc. This, being reckoned as negative power, is plotted below the zero line, as shown in the complete curve Fig. 30.

Owing to the particularly low speed of winding chosen, it will be seen that there will be insufficient kinetic energy in the system to bring the load to rest at the proper place, if the current is cut off at the point marked; and it will therefore be necessary, if these values are adopted, to reduce the power gradually, as the load approaches its destination, the current being cut off and the brakes applied within four or five seconds only of the end of the wind.

All winding engines are provided with a depth indicator, so that the driver can see at a glance the position of the cages, and, from this, he knows when to cut off his current and apply the brakes.

The above example represents a very simple case, but the method adopted will be the same for all. The shape of the curve will, however, vary greatly according to circumstances. For instance, with a high winding speed, and a short acceleration period, the curve would have a very high peak at starting, while, with a very deep pit, the weight of the rope may be sufficient to assist the motor towards the end of the winding period, and the brakes will not only have to absorb the kinetic energy, but will have to bring the load to rest against the extra pull of the descending cage and rope.

With very deep pits the great length and weight of the ropes against the load at starting puts a big strain on the motor and generating plant, and, for this reason, it is sometimes customary to balance the main rope by a tail rope below the cages. Another method is to use a conical drum, so that the ascending load starts to wind on a small diameter, while the descending load commences to unwind on a large diameter, thereby wholly or partially balancing the unequal lengths and weights of the ropes.

In our example we assumed a parallel drum, which is the pattern usually adopted; but, for a very deep pit, the parallel drum has to be of considerable diameter in order to accommodate the necessary amount of rope, for it is unusual to arrange the rope in more than one layer on the drum. If the drum is too wide there is difficulty on account of the angularity of ropes and head gear pulleys, and this has a detrimental effect on the life of the ropes.

Fig. 31 shows the various types of drum designed to overcome these objections.

"*A*" is the plain parallel drum, which is the simplest pattern, the ropes being wound in opposite directions so that one unwinds as the other winds up.

"*B*" shows the conical drum, which commences to wind the full cage, and long rope, on a small diameter while the empty cage and short rope are suspended on the large. The diameters of this type of drum are so chosen that the ropes will balance throughout the whole of the winding period. The chief objection to the type is its large diameter and great weight, which of course make the drum itself very expensive, while all the energy put into the drum at starting to bring it up to speed must be wasted by braking when bringing the load to rest.

"*C*" depicts the spiro-parallel drum, which is really a compromise between the conical and the parallel patterns. It is practically a parallel drum, but, at either end, there will be a few turns of the rope on the small diameter, which quickly ascends to the parallel part of the drum in three or four revolutions. The heavy load starts to wind up on the small diameter, while the light load winds off the large diameter. The ropes will not be balanced throughout the wind as with the conical drum, but the conditions are in favour of starting at the commencement, and also in favour of stopping at the end of the wind. The drum is smaller in diameter, lighter, and cheaper than the conical drum.

"*D*" shows the Keope pulley which has the merits

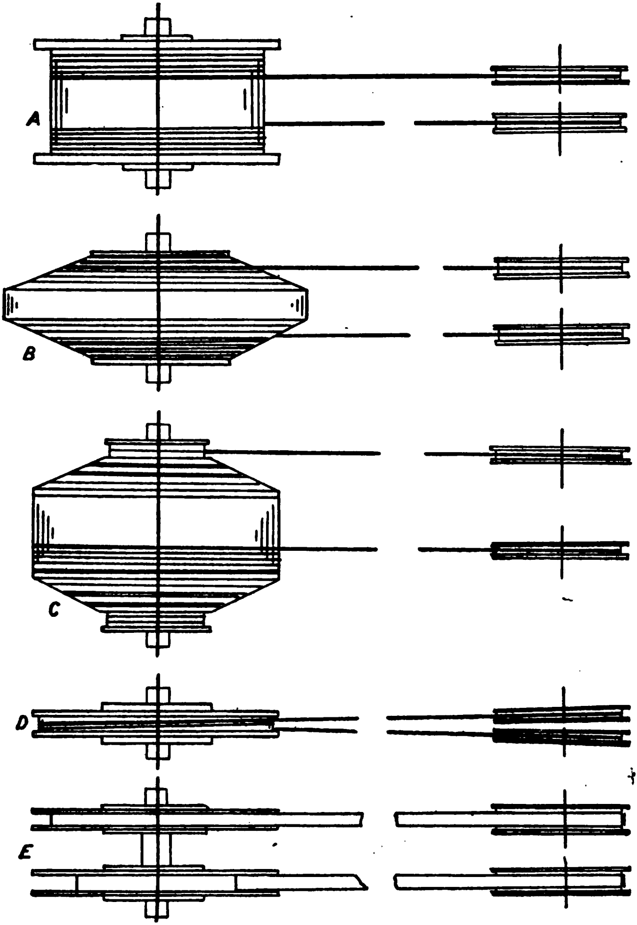

FIG. 31. TYPES OF WINDING DRUMS.

of simplicity and of light weight. It consists of a simple grooved pulley in which the rope lies, one cage being attached to each end of the rope, and balancing effected by means of tail ropes. The system has not been used in this country because of the possibility of the rope breaking, in which case there is nothing to save both cages from falling. Other modifications have been tried, one of which is known as the "Whitting" system, but it is not likely to come into use in this country for collieries.

"*E*" indicates the reel drums as used on the Continent. In this case the ropes are flat and can be arranged to balance, while the drums are comparatively light.

With electric winding engines the shape of the drum determines, to a great extent, the shape of the horse-power curve, and also the maximum loads that are likely to occur on the motors and generating plant.

The speed and acceleration also have a great influence in determining the shape of the horse-power curve; and all these points can only be decided upon for any particular installation, when full particulars of the duty required and limitations of the mine are available.

Briefly, the chief object is to bring up the required amount of coal in the given time, with as small an expenditure of energy as possible, consistent with maintaining a good average continuous load on the generating plant.

In most cases it is only possible to arrive at the best solution after several trials on paper; but before one can attempt the problem, full particulars regarding the capacity and limitations of the mine must be available.

Most mines in this country are considerably deeper than that in our example, and, in order to bring up the full amount of coal in the given time, quick winding speeds and high rates of acceleration must be adopted. The amount of coal that can be brought up at a time is limited by the capacity of the trucks used, this capacity being dependent upon the thickness of the seams worked.

The diameter of the shaft determines the number of trucks per deck, while the method of handling the trucks fixes the time required at each wind for changing.

In a deep mine a rope speed of forty miles an hour is not uncommon, while the acceleration may be 6 ft. per second per second. An electric winding engine to deal with a heavy load under such conditions presents a difficult problem, and several patented systems have been brought out, the chief feature of which is the flywheel storage plant. With this arrangement, the generating plant runs under approximately even load all day, the heavy demand for power during the acceleration period being taken from the flywheel set, this energy being put back during the time current is not required on the winding motor, thereby preserving an approximately even load on the generating plant.

Motors operating electric winding engines may be of the continuous current, three-phase, or two-phase type. If the plant is simple, the motors may be controlled by means of a standard controller as described for haulage gears. One point must not be lost sight of in connexion with the design of the resistances. They must allow of running the motors at a suitable speed for lowering and raising the men, and they should also be capable of giving a very slow speed for examining the shaft.

The brake gear must necessarily be well designed, and, in addition to the ordinary service brake, an emergency brake is usually provided, this being set in action by the winding indicator if the driver fails to stop the cages in time. It is also usual for the emergency brake to come into operation when the speed exceeds a predetermined limit.

CHAPTER XI

ELECTRIC WINDING SYSTEMS

As already pointed out in the previous chapter, all electric winding plants (except very small installations, operating under the most advantageous circumstances as regards winding) would give rise to a load curve of an objectionable description as viewed from the generating station point of view.

With the idea of obtaining the most advantageous conditions of winding, together with a more or less even load on the generating plant, several electric winding systems have been developed. In all cases the main principle is the same, namely, that of storing energy during such times as there is little or no load on the winding engine, this energy being given up again at the time of greatest need (i.e. during acceleration) to assist the main generators. With a properly designed system, working under such conditions, the main generating plant will run continuously throughout the working day under approximately constant load.

The various systems differ in their manner of storing the energy, but most makers use a heavy flywheel; although secondary batteries have been proposed, and have some advantages.

We will deal first with the flywheel storage systems. It is well known that the energy stored in a revolving flywheel is given by the formula $M \times V^2 \div 2$.

Where $M =$ the mass of the rim (lb. $\div$ 32·2), and $V =$ the velocity in feet per second.

The result is in foot-pounds of energy stored in the wheel. From this it will be seen that the energy is proportional to the weight of the rim of the wheel and to the square of its speed. These flywheels are usually made of steel plate, and are run at as high a speed as possible, consistent with safety.

It is evident that while a flywheel runs at constant speed, no energy is added to or taken from the system. In order to take any energy out of the wheel the speed must be decreased, and, conversely, if energy be added to the wheel the speed is increased.

In adapting this principle to electric winding plants, we alternatively store energy in and extract it from the wheel, the speed varying accordingly. The useful work put into or taken from the system depends upon the difference between maximum and minimum speeds, and is given by the formula :—

$$M\ (V^2 - v^2) \div 2 = \text{foot-lbs.}$$

A calculation based on any case in practice will show at once that it requires a very heavy wheel, running at a good speed, to obtain the desired results, because it is not possible to have too great a variation between the maximum and minimum speeds of the flywheel storage set.

The above represents the problem from a mechanical point of view, and it is chiefly in connexion with the methods of driving the flywheel set electrically, and regulating its speed according to the demand, that the various systems now described have been evolved.

Perhaps the best known is the Siemens-Ilgner System, which has been developed by Messrs. Siemens Schuckertwerke in Germany, and Messrs. Siemens Brothers Dynamo Works, Limited, in this country.

The diagram, Fig. 32, illustrates the general features. From the mains, or from an electric power station, is drawn the current for driving a motor generator or converter, consisting of a motor coupled to a dynamo.

This converter transforms the supply current into continuous current at variable voltage, which is used for driving the winding motor. The supply may be either alternating on the two- or three-phase system, or continuous current, whichever happens to be available from power station or supply company.

The converter motor is built to suit the character of the supply, but the diagram, Fig. 32, shows a three-phase motor with slip rings, the starting panel with main switches being at (*a*) and the rotor starting resistance at (*c*).

The converter is provided with a heavy flywheel in the form of a single steel casting, or forging, which is capable of running with safety at a high circumferential velocity. The energy stored in this flywheel is drawn upon for taking up fluctuations in the load of the winding engine, and equalizing the load upon the generating plant.

The converter generator and the winding motor are both of the continuous-current type. They are separately excited, and, when the supply is alternating, a small direct-coupled dynamo provides the necessary excitation current.

The armatures of the winding motor and the converter generator are connected in series, and a set of regulating resistances is provided, by means of which the exciting current of the converter generator is varied from zero to a positive or negative maximum. The degree of excitation determines the voltage generated, and applied to the terminals of the winding motor armature, and the revolutions of the latter vary in direct proportion.

The winding motor is either direct-coupled to the drum, or drives through single-reduction spur gearing. The former has the advantage of simplicity of construction, and freedom from noise when working, and is generally used for all plants of large size; for smaller plants, however, it is more costly than the geared arrangement. In very large plants, two coupled motors, one on either side of the winding

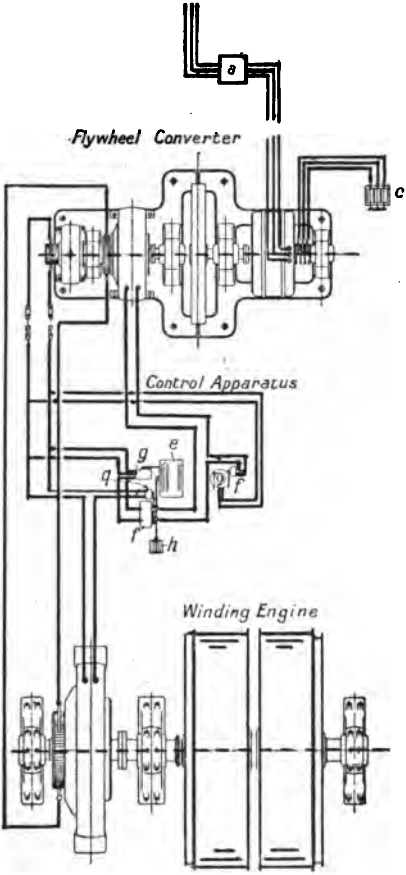

FIG. 32. SIEMENS-ILGNER WINDING SYSTEM.

drum, are sometimes used. This arrangement is chiefly advantageous in giving extra security against breakdown since, in an emergency, one motor can be used to wind at half speed.

As already mentioned, the complete system is controlled by the regulating apparatus, a control lever being provided for working the field rheostat in the excitation circuit of the converter generator. As this field rheostat controls the excitation current from zero to a positive or negative maximum, it is evident that reversal of the winding motors is effected by moving the control lever to one side or the other from its "off" position. This regulator is provided with a large number of steps, in both directions, so that exceedingly small gradations of speed are obtainable. By moving the controller only a small amount from the central position, the cages can be driven at a creeping speed which is necessary for inspecting the shaft. By moving the control lever a greater distance, the acceleration and winding speed are increased to any desired and predetermined value for which the plant may be designed.

Another special feature of the system is the "regenerative braking." Assume the engine to be in operation, and winding at full speed; then, by moving the control lever back toward the central position, the excitation of the converter motor-generator is reduced, until its electro-motive force falls below the back electro-motive force of the winding motors. The latter act as generators, and tend to bring the gear to rest, while, at the same time, it replenishes energy and increases the speed of the flywheel set.

In addition to this regenerative braking action other brakes are used, similar to those employed with steam winding engines, except that they are operated by compressed air, supplied by a small electrically driven compressor.

Fig. 33 shows an actual load diagram, taken from an electric winding engine. The high peaks, at the commencement of each cycle, show the power taken during the acceleration periods, while the other curve

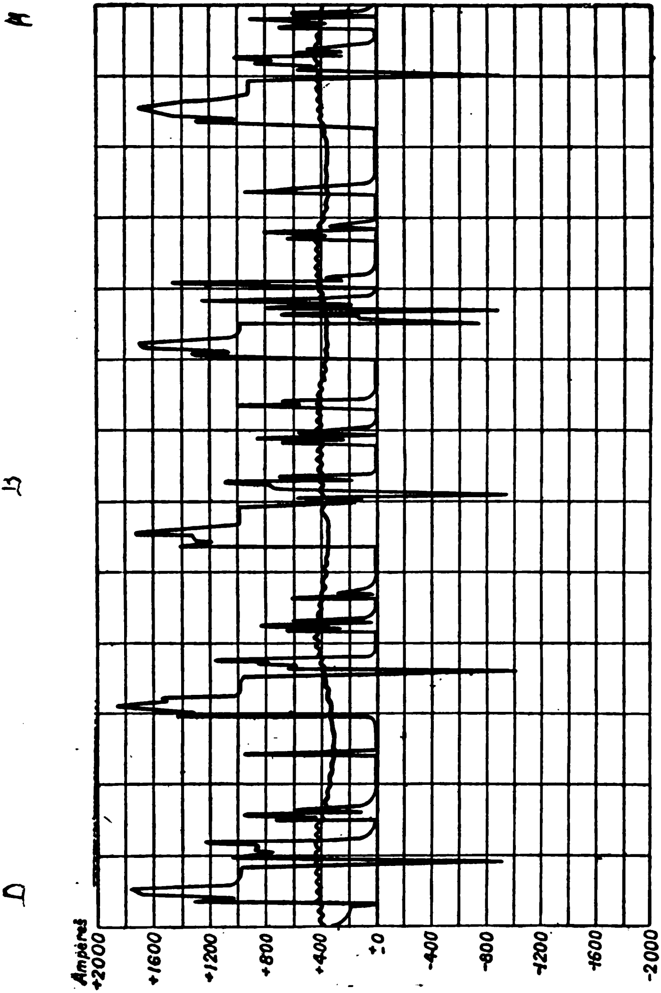

FIG. 33. WINDING ENGINE LOAD CURVE.

shows how the load has been maintained approximately constant on the generating plant, all the time the winding engine is in use.

As an illustration of an electric winding system employing secondary batteries as load equalizer we may instance that designed by Messrs. Crompton and Co. The diagram, Fig. 34, shows the arrangement of the connexions. In this particular case a three-phase supply is shown, but it will obviously make no difference to the principle, if the supply be on any other system.

There are two continuous current motors, direct coupled to the winding drums. The armatures of these motors are connected in series, and provided with a reversing switch, the position of which determines the direction in which they should run.

The fields have two separate exciting coils, one being connected between the main leads from the omnibus bars in the generating station, and the other from a point between the armatures of the two motors to one of the leads from the omnibus bars.

These motors are supplied with energy through a special motor generator, the function of which is to give automatic and hand control over the voltage at the terminals of the motors, without the necessity or troublesome and wasteful series resistances, and, consequently, to give a very wide range of control over the motor speeds.

The motor generator consists of two continuous-current machines, one being an ordinary shunt motor supplied with power from the mains.

This special generator is in series with the main source of supply, and is consequently able to increase or diminish the voltage of the main supply, according to whether it is excited in one direction or the other; and, by special windings, is able to give a wide range of hand control as well as an automatic control, over the volts added to or deducted from the main supply.

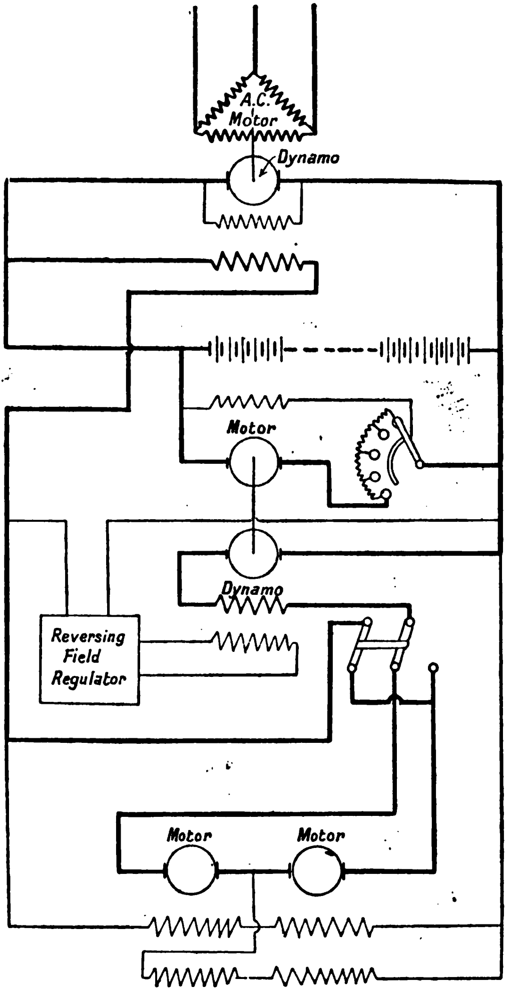

FIG. 34. CROMPTON WINDING SYSTEM.

To produce this result the generator portion of the motor generator has two field windings, one being a separately exciting circuit, taken from the main omnibus bars through the agency of a reversing and regulating switch, which gives a full range of adjustment between a maximum in one direction down to zero, and, further, to a maximum in the opposite direction.

This field excitation is supplemented by a special limiting coil, connected in series with the generator and the motors, and wound in such a direction that, by partially or entirely neutralizing the supply voltage it entirely prevents the current through the motors, under any circumstances, from exceeding a definite pre-determined amount.

The motor-generator and motors take their power from any ordinary continuous-current generating plant, which, however, should preferably be provided with a storage battery, and automatic reversible booster, as used in tramway stations.

The diagram above referred to illustrates the case of a three-phase supply system, in which it becomes necessary to provide another motor-generator set to convert three-phase current into medium tension continuous current. A small storage battery is used in parallel with the continuous-current machine, and the fields of this latter are wound in such a way as to draw the extra current, required for acceleration, from the battery, and not from the supply source; also to return the extra current, generated during braking, to the battery and not to the supply. There may be cases where a storage battery is not required; for instance, as the winding is only a small proportion of the total continuous current load of the colliery, the return currents go out to the other machines and simply relieve the main dynamo of its load; but in most cases the battery is recommended.

The working of the system is as follows:—

When the cage is at rest the reversing switch may be in either position, and the regulator, already described, is in such a position that the motor generator completely neutralizes the supply voltage; consequently, although the main circuit to the motors is made, no current flows through them, and there is no movement of the cage; in fact, the cage, under these circumstances, is electrically locked, and unable to move.

When it is desired to commence winding, the reversing switch is set to the required position, which may be done without opening the main circuit. The regulator is then moved so as to allow the generator to neutralize less of the supply volts, until they attain their maximum value, and afterwards to increase them until their value is doubled.

It is immaterial whether this operation is carried out slowly as the motor speeds up, or quickly, for if at any time it is so moved as to produce a tendency for the generating plant to give the motors too much current, the limiting coil on the motor generator comes into action, and at once reduces the voltage and keeps the motor current down to the predetermined amount.

Under these circumstances the motors are supplied with a constant armature current, adjusted to a figure which has been found most suitable for giving the acceleration required to bring the speed of the cage up to its maximum in the shortest possible time.

When the cage is standing, the motor armatures are receiving no current, but their fields are at maximum strength. *B* coil is constant, remaining at the same strength under all circumstances, and *C* coil under these conditions is subjected to a voltage equal to the supply voltage, and these two excitations give full field strength, which enables the armature to hold the cage in position, and, when required, gives the maximum possible starting torque. The conditions for acceleration are ideal. At first the field is at maximum strength and the volts on the armatures automatically adjusted to give the required acceleration without the current exceeding the limiting figure.

It will be noticed that accelerating power is obtained by increasing the field strength instead of by increasing the armature current, as in ordinary series-parallel or series motor systems. This makes a great deal of difference in the design of the motor, and enables the efficiency of the motor under these conditions to be at its maximum, besides dispensing with starting resistances, which are wasteful.

When the cage attains its full speed the volts on the armatures are double the volts of the supply, and the fields are weak owing to the fact that *C* coil is now doing nothing.

When it is required to reduce the speed and stop, the regulator on the motor generator is reversed so that the voltage supply to the motors is lowered. The motors will then commence to run as generators and return current to the generating plant, which is either used by other machines or absorbed by the storage battery.

The fields of the motors begin to strengthen owing to *C* coil again coming into use, which maintains the power returned to the supply. This return power is, however, limited in the same way as was the accelerating current, owing to the action of the limiting coil on the motor generator, so that the return current and the braking effort are kept within a certain predetermined limit.

Under these conditions the cage rapidly loses speed and can be brought to rest definitely and held in position at the proper place.

In the two foregoing systems of electric winding it will be noted that continuous current is supplied to the motors driving the winding drums. In the Westinghouse Converter Equalizer system now described, three-phase motors are used to drive the winding drums. This arrangement has an advantage over that in which the current is first converted to continuous current, inasmuch as the winding motors may still be operated in the event of the equalizer or flywheel set breaking down.

As shown in Fig. 35, the general arrangement of the Westinghouse system consists of a rotary converter (1) connected through transformers (2) to the transmission line. On its continuous current side the rotary converter is connected to a continuous-current machine; (3) acting sometimes as a generator

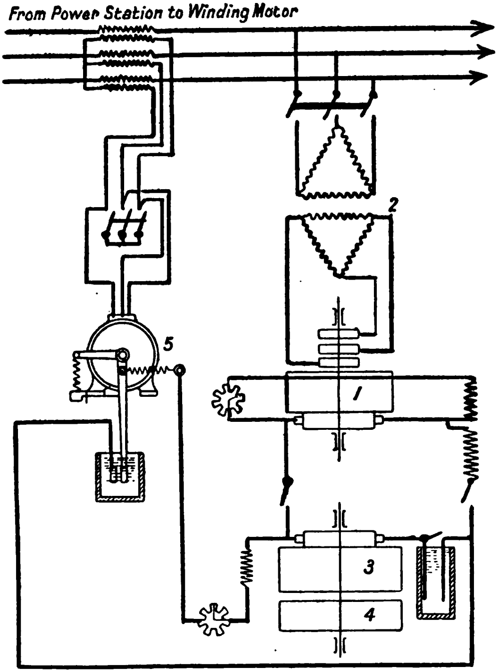

FIG. 35. WESTINGHOUSE WINDING SYSTEM.

and sometimes as a motor, and fitted with a flywheel (4).

The rotary converter is compounded in a special way so as to supply, automatically, the magnetizing currents required by the induction motors on the system. The voltage of the continuous current flywheel machine (3) is controlled automatically by a quick acting regulating apparatus (5) which is actuated from the transmission line through a series transformer. The whole arrangement constitutes a "converter equalizer," the action of which is to discharge energy into the high tension system whenever the load on the latter is greater than the constant output; and to store energy in the flywheel whenever the power demand from the high tension supply system is less than the constant output of the station.

When there is no load on the high tension system, the rotary converter runs with approximately 100 per cent. power factor, and gives up to the flywheel—through the medium of the continuous-current machine acting as a motor—energy corresponding to the constant output of the station, until maximum speed is reached. The flywheel is built for high speeds, in order to obtain the necessary effect with a minimum of weight, and the slip may be anything up to 30 per cent. or 40 per cent. if necessary.

This converter equalizer may be applied to the three-phase system at any point, and three-phase current taken from the system will then be governed by it. In using the equalizer for electric winding engines, three-phase winding motors are employed, and any number may be connected to the system of which the equalizer forms a part. Several electric winding engines may therefore be put down to work in conjunction with one equalizer, and, further, the latter may be placed in any convenient position and need not necessarily be installed in the winding engine house.

It will be evident, on further consideration, that this system differs in some important respects from the Ilgner and Crompton systems just described. In both these cases the whole of the electrical energy is converted, by means of the motor generators provided, while in the Westinghouse converter equalizer system, only that amount of energy is transformed into continuous current, and back into three-phase current, which is in excess of, or below, the constant output of the station. It stands in the same relation to the three-phase system as the air chamber to a plunger pump, and, in like manner, the system may be operated at any time without the equalizer if necessary.

In order to clearly explain the operation of the winding engine with this system of control, Fig. 36 has been prepared, partly perspective and also diagrammatic. The drum or friction brakes are normally actuated by the compressed air cylinder (*B*) or, in cases of emergency, by the weighted lever (*C*). The whole control gear is operated by means of three levers which are fixed on the driver's platform.

The lever (*a*) on the driver's right, actuates the main reversing switch and the liquid starting rheostat. The lever can be moved either forward or backward from its central or off position, the condition of the main reversing switch (*o*) and, consequently, the direction of rotation, depending upon this movement. As soon as the lever is moved, either way, the main reversing switch is first operated, and then the liquid starting rheostat.

The latter consists of two tanks, mounted one above the other, together with a small motor and circulating pump as shown in the illustration. The upper tank contains three stationary electrodes, and a movable sluice gate, the electrodes being connected to the slip rings of the main motor. The lower tank holds a supply of resistance liquid, and is fitted with pipes through which cooling water is circulated.

The liquid is transferred into the upper tank by

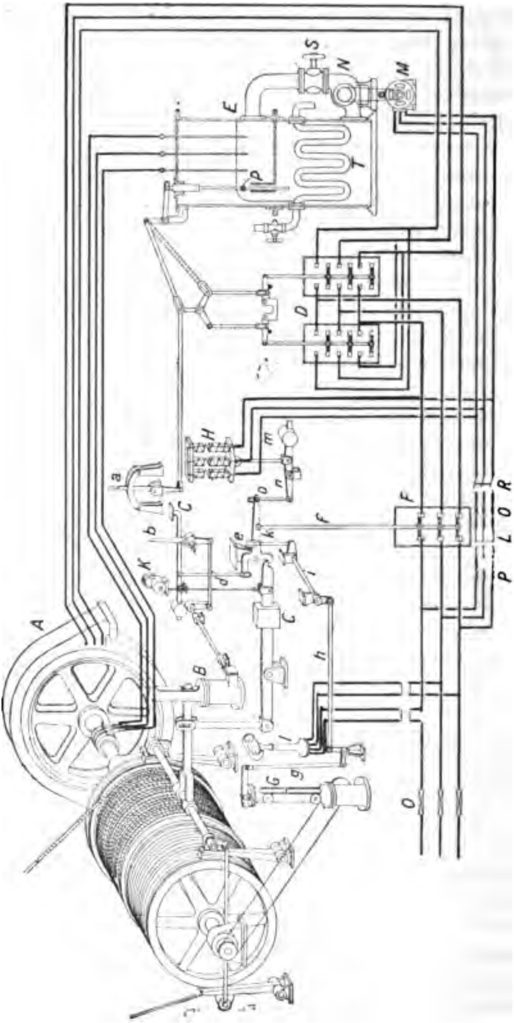

FIG. 36. WESTINGHOUSE WINDING ENGINE AND CONTROL GEAR.

means of the circulating pump and returns to the lower, over the sluice gate, which is in its lowest position when the driver's operating lever is off.

Following on the first movement of the control lever—which throws the main reversing switch into one position or the other, according to the required direction of rotation—the sluice gate is raised. This causes the level of the liquid in the upper tank to rise, and, consequently, decreases the resistance between the slip rings.

The sluice gate may be checked in any position, or it may be immediately thrown to its highest point, this depending on how the driver operates his lever; as, however, the liquid cannot follow the raised sluice gate faster than the pump can raise the liquid into the upper tank, a certain maximum acceleration of the motor cannot be exceeded, although any less acceleration may be obtained. This maximum acceleration is adjustable by means of a stop valve in the delivery pipe of the pump.

The lever (*b*) on the driver's left, operates the pneumatic brake. The design of the control gear is such that electrical braking of the motor, when lowering, may be arranged for if necessary.

The foot lever (*c*) is placed in a position between the hand levers, so that complete control is all within easy reach of the driver. This pedal releases the weighted brake lever, and also opens the emergency switch (*f*), thus cutting off the supply of current to the motor.

Provision is also made for stopping the plant in the event of overwinding, or a failure of the electricity supply. The former is effected by tripping mechanism in connexion with the depth indicator; while an abnormal fall in voltage, or failure of the supply, causes the cores of solenoid (*H*) to drop, and release the emergency brake and switch.

Replacement of the weighted lever (*C*) is provided for by means of a small winch shown at (*K*).

Although the technical description of the foregoing winding systems are somewhat intricate, the actual operation of such a plant, from the driver's point of view, is very simple. In fact, it is simpler than the steam winder, and, further, the protective and emergency devices provided, compel the driver to work his plant properly, while any accident that might possibly occur is safeguarded to an extent which is impossible with the steam winder.

CHAPTER XII

Special rules for the installation and use of electricity.

THE following Rules shall be observed, as far as is reasonably practicable, in the mine.

DEFINITIONS

The expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and earth, as read by a hot wire or electrostatic voltmeter and—

(*a*) Where the conditions of the supply are such that the pressure at the terminals where the electricity is used cannot exceed 250 volts, the supply shall be deemed a low-pressure supply.

(*b*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 250 volts, but cannot exceed 650 volts, the supply shall be deemed a medium-pressure supply.

(*c*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used between any two conductors, or between one conductor and earth, may at any time exceed 650 volts, but cannot exceed 3,000 volts, the supply shall be deemed a high-pressure supply.

(*d*) Where the conditions of supply are such that the pressure at the terminals where the electricity is used, between any two conductors, or between one conductor and earth, may at any time exceed 3,000 volts, the supply shall be deemed an extra high-pressure supply.

SECTION I

GENERAL

1. (*a*) All electrical apparatus and conductors shall be sufficient in size and power for the work they may be called upon to do, and, so far as is reasonably practicable, efficiently covered or safeguarded, and so installed, worked, and maintained, as to reduce the danger through accidental shock or fire to the minimum; and shall be of such construction, and so worked, that the rise in temperature caused by ordinary working will not injure the insulating materials.

(*b*) In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the covering shall be constructed so that, as far as is reasonably practicable, there is no danger of firing gas by sparking or flashing, which may occur during the normal or abnormal working of the apparatus.

(*c*) All metallic coverings, armouring of cables, other than trailing cables, and the frames and bedplates of generators, transformers, and motors other than portable motors shall, as far as is reasonably practicable, be efficiently earthed where the pressure at the terminals where the electricity is used, exceeds the limits of low pressure.

2. Where a medium-pressure supply is used for power purposes, or for arc lamps in series, the wires or conductors forming the connexions to the motors, transformers, arc lamps or otherwise in connexion with the supply, shall be, as far as is reasonably practicable, completely enclosed in strong armouring or metal casing, efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner, that danger from fire or shock may be reduced to the minimum. This rule shall not apply to trailing cables.

3. Where a medium-pressure supply is used for incandescent lamps in series, the wires or conductors forming connexions to the incandescent lamps, or otherwise in connexion with the supply, shall be, as far as is reasonably practicable, completely enclosed in strong armouring or metal casing, efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner that danger from fire or shock shall be reduced to the minimum.

4. Motors of coal-cutting and such other portable machines shall not be used at a pressure higher than medium pressure. No transformer used for supplying current at a pressure higher than medium pressure, and no motor using such current, shall be of less normal rating than 20 B.H.P. for use underground.

No higher pressure than a medium pressure shall be used in any place or part of the mine to which General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies.

5. No higher pressure than a medium-pressure supply shall be used other than for transmission or for motors, and the wires or conductors other than overhead lines above ground, forming the connexions to the motors or transformers, or otherwise in connexion with the supply, shall be completely enclosed in a strong armouring or metal casing, efficiently connected with earth, or they shall be fixed at such a distance apart, or in such a manner that danger

from fire or shock shall be reduced to the minimum.

The machines, apparatus, and lines shall be so marked as to clearly indicate that they are high pressure, either by the use of the word "Danger" at frequent intervals, or by red paint properly renewed when necessary.

6. The insulation of every complete circuit other than telephone or signal wires, used for the supply of energy, including all machinery, apparatus, and devices forming part of or in connexion with such circuit, shall be so maintained that the leakage current shall, so far as is reasonably practicable, not exceed $\frac{1}{1000}$ of the maximum supply current, and suitable means shall be provided for the immediate localization of leakage.

7. In every completely insulated circuit, earth or fault detectors shall be kept connected up in every generating and transforming station, to show immediately any defect in the insulation of the system. The readings of these instruments shall be recorded daily in a book kept at the generating or transforming station or switch-house.

8. Main and distribution switch and fuse boards must be made of incombustible insulating material, such as marble or slate free from metallic veins, and be fixed in as dry a situation as practicable.

9. Every sub-circuit must be protected by a fuse on each pole. Every circuit carrying more than 5 amperes up to 125 volts, or 3 amperes at any pressure above 125 volts, must be protected in one of the following alternative methods:—

(*a*) By an automatic maximum cut-out on each pole.

(*b*) By a detachable fuse on each pole, constructed in such a manner that it can be removed from a live circuit with the minimum risk of shock.

(*c*) By a switch and fuse on each pole.

10. Fire buckets, filled with clean, dry sand, shall

be kept in electrical machine rooms, ready for immediate use in extinguishing fires.

No repair or cleaning of the live parts of any electrical apparatus, except mere wiping or oiling, shall be done when the current is on.

Gloves, mats, or shoes of india-rubber or other non-conducting material shall be supplied and used where the live parts of switches or machines working at a pressure exceeding the limits of low pressure, have to be handled for the purpose of adjustment.

11. A competent person shall be on duty at the mine when the electrical apparatus or machinery is in use; and at such time as the amount of electricity delivered down the mine exceeds 200 B.H.P., a competent person shall be on duty at the mine above ground, and another below ground. Every person appointed to work any electric apparatus shall have been instructed in his duty and be competent for the work that he is set to do.

12. No person shall wilfully damage, interfere with, or without proper authority, remove, or render useless, any electric line, or any machine, apparatus, or part thereof, used in connexion with the supply or use of electricity.

13. Instructions shall be posted up in every generating, transforming, and motor house, containing directions as to the restoration of persons suffering from electric shock.

14. Direct telephonic or other equivalent means of communication shall be provided between the surface and the pit bottom, or main distributing centre in the pit.

15. Within three months after the introduction into any mine of electric motive power, notice in writing must be sent to H.M. Inspector of Mines for the district. Notice must also be sent of any existing electric motive power installation at any mine within three months after the coming into force of these rules.

16. A plan shall be kept at the mine showing the position of all permanent electrical machinery and cables in the mine, and shall be corrected as often as may be necessary to keep it up to a date not more than three months previously.

SECTION II

GENERATING STATIONS AND MACHINE ROOMS

17. Where the generating station under the control of the owner or manager of the mine is not within 400 yds. of the working pit mouth, an efficiently enclosed locked switch box or boxes, or a switch house, shall, where reasonably practicable, be provided near the pit mouth, for cutting off the supply of electricity to the mine.

18. There shall be a passage way in front of the switch board of not less than 3 ft. in width, and if there are any connexions at the back of the switchboard, any passage way behind the switchboard shall not be less than 3 ft. clear. This space shall not be utilized as a storeroom or a lumber room, or obstructed in any manner by resistance frames, meters, or otherwise. If space is required for resistance frames or other electrical apparatus behind the board, the passage way must be widened accordingly.

No cable shall cross the passage way at the back of the board except below the floor, or at a height of not less than 7 ft. above the floor.

The space at the back of the switchboards shall be properly floored, accessible from each end, and, except in the case of low-pressure switchboards, must be kept locked up, but the lock must allow of the door being opened from the inside without the use of a key. The floor at the back shall be incombustible, firm, and even.

19. Every generator shall be provided with a

switch on each pole between the generator and the busbars.

Where continuous-current generators are paralleled, reverse current cut-outs shall also be provided.

Suitable instruments shall be provided for measuring the current and pressure of each generator.

Every feeder circuit shall at its origin be provided with an ammeter.

20. If the transmission lines from the generating station to the pit are overhead, there shall be lightning arresters in connexion with the feeder circuits.

21. Automatic cut-outs must be arranged so that when the contact lever opens outwards no danger exists of striking the head of the attendant. If unenclosed fuses are used they must be placed within 2 ft. of the floor, or be otherwise suitably protected.

Where the supply is at a pressure exceeding the limits of medium pressure, there shall be no live metal work on the front of the main switchboard within 8 ft. of the floor or platform, and the space provided under Rule No. 2 of this section shall be not less than 4 ft. in the clear. Insulating floors or mats shall be provided for medium pressure boards where live metal work is on the front or back.

22. All terminals and live metal on machines over medium pressure above ground, and over low pressure under ground, where practicable shall be protected with insulating covers or with metal covers connected to earth.

23. No person other than an authorized person shall enter a machine or motor room, or interfere with the working of any machine, motor, or apparatus connected therewith.

SECTION III

CABLES

24. All conductors (except as hereinafter provided) shall in every case be maintained completely

insulated from earth, but it is permissible to use the concentric system with earthed outer conductor, if proper arrangements are made to reduce the danger from fire or shock to the minimum; but the neutral point of polyphase systems, and the middle wire of three-wire continuous-current systems may be earthed at one point.

25. Unless fixed as far as is reasonably practicable out of reach of injury, all conductors, other than armoured cables, must further be protected by a suitable covering. Where lead-covered cable is used the lead shall be earthed, and electrically continuous throughout.

The exposed ends of cables where they enter the terminals of switches, fuses, and other appliances, must as far as is reasonably practicable, be properly protected and finished off, so that moisture cannot creep along the insulating material within the waterproof sheath, nor can the insulating material, if of an oily nature, leak out of the cable.

26. All joints must be mechanically and electrically efficient, and, where reasonably practicable, must be suitably soldered. In any place or part of the mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, suitable joint boxes must be used, and the conductors connected by means of metal screw clamps, connectors, or their equivalent, constructed in a safe manner. Provided that in any place or part of a mine where a shot may be fired, joints may be soldered by, or in the presence of, a person authorized in that behalf by the manager; but the same precautions in regard to examination and removal of workmen as are prescribed by paragraphs (*f*) and (*i*) of General Rule 12 shall be observed in all cases, and where the place is dry and dusty, also the precautions as to watering prescribed in paragraph (*h*). Wires, other than signalling wires, or cables, must not be joined by merely twisting them together.

27. Overhead bare wires on the surface must be efficiently supported upon insulators, and clear of any traffic, and provided with efficient lightning arresters.

28. All cables used in shafts must be highly insulated and substantially fixed. Shaft cables, not capable of sustaining their own weight, shall be properly supported at intervals varying according to the weight of the cable. Where the cables are not completely boxed in and protected from falling material, space shall be left between them and the side of the shaft that they may yield, and so lessen a blow given by falling material.

29. Where the cables in main haulage roads cannot be kept at least 1 ft. from any part of the tub or tram, they shall be specially protected. When separate cables are used they shall, if reasonably practicable, be fixed on opposite sides of the road.

The fixing, with metallic fastenings, of cables and wires not provided with metallic covering, to walls or timbers, is prohibited.

Cables underground, when suspended, shall be suspended by leather, or other flexible material, in such a manner as to allow of their readily breaking away when struck, before the cables themselves can be seriously damaged.

Where main or other roads are being repaired, or blasting is being carried out, suitable temporary protection must be so used that the cables are reasonably protected from damage.

30. Trailing cables for portable machines shall be specially flexible, heavily insulated, and protected with either galvanized steel wire armouring, extra stout braiding, hose pipe, or other effective covering. Trailing cables shall be examined at least once in each shift by the person in charge of the machine, and any defects in them promptly repaired.

At points where the flexible conductors are joined to the main cables, a fixed terminal box must be provided, and a switch shall be fixed close to or in the terminal box capable of entirely cutting off the supply from the terminal box and motor.

SECTION IV

SWITCHES, FUSES AND CUT-OUTS

31. Fuses and automatic cut-outs shall be so constructed as effectually to interrupt the current when a short circuit occurs, or when the current through them exceeds the working current by 200 per cent. Fuses shall be stamped or marked, or shall have a label attached, indicating the current with which they are intended to be used, or where fuse wire is used each coil in use shall be so stamped or labelled. Fuses shall only be adjusted or replaced by an authorized person.

32. All live parts of switches, fuses, and cut-outs, not in machine rooms or in compartments specially arranged for the purpose, must be covered. These covers must be of incombustible material, and must be either non-conducting or of rigid metal, as far as practicable, clear of all internal mechanism.

33. All points at which a circuit, other than those for signals, has to be made or broken, shall be fitted with proper switches. The use of hooks or other makeshifts is prohibited, and in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the use of open-type switches, fuses, and cut-outs is prohibited; they must either be enclosed in gas-tight boxes, or break under oil.

SECTION V

MOTORS

34. All motors, together with their starting resistances, shall be protected by switches capable of

entirely cutting off the pressure, and fixed in a convenient position near the motor; and every motor of 10 B.H.P. or over, in a machine room underground, shall be provided with a suitable ammeter to indicate the load put upon the machine.

35. Where unarmoured cables or wires pass through metal frames or into boxes or motor casings, the holes must be substantially bushed with insulating bushes, and, where necessary, with gas-tight bushings which cannot readily become displaced.

36. Terminal boxes of portable motors must be securely attached to the machine, or be designed to form a part thereof.

37. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, all motors, unless placed in such rooms as are separately ventilated with intake air, shall have all their current-carrying parts, also their starters, terminals, and connexions, completely enclosed in flame-tight enclosures, made of uninflammable material, and of sufficient strength as not to be liable to be damaged should an explosion of firedamp occur in the interior, and such enclosures shall not be opened except by an authorized person, and then only when the current is switched off. The pressure shall not be switched on while the enclosures are open.

38. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, a safety lamp or other suitable apparatus for the detection of firedamp shall be provided for use with each machine when working, and should any indication of firedamp appear on the flame of the safety lamp or other apparatus used for the detection of firedamp, the person in charge shall immediately stop the machine, cut off the current at the gate end or nearest switch, and report the matter to an official of the mine.

39. (*a*) A coal-cutter motor shall not be kept continuously at work for a period of time exceeding

a maximum period which shall be specified in writing by the manager, so that the roof may be carefully examined.

(*b*) The casing or inspection doors of all portable motors used underground and the casings of their switches and other appliances shall at least once a week be opened by a competent person appointed by the manager, and the parts so disclosed shall be cleaned and examined before the coverings are replaced. In special cases requiring a motor to run continuously, longer than one week, the motor shall be examined at the end of the run. A report of such examination shall be entered in a report book.

40. The person in charge of a coal-cutter or drilling machine shall not leave the machine while it is working, and shall, before leaving the working place, see that the current is cut off from the trailing cables. He must not allow the cables to be dragged along by the machine. No repairs shall be made to any portable machine until the pressure has been cut off from the trailing cables.

41. If any electric sparking or arc be produced outside a coal-cutting or other portable motor, or by the cables or rails, the machine shall be stopped, and not be worked again until the defect is repaired, and the occurrence shall be reported to an official of the mine.

SECTION VI

ELECTRIC LOCOMOTIVES

42. Electric haulage by locomotives by the trolley wire system is not permissible in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies. On this system no pressure exceeding the limits of medium pressure may be employed.

43. In underground roads the trolley wires must

be placed so that they are at least 7 ft. above the level of the road or track, or elsewhere, if sufficiently guarded, or the pressure must be cut off from the wires during such hours as the roads are used for travelling on foot in places where trolley wires are fixed. The hours during which travelling on foot is permitted shall be clearly indicated by notices and signals placed in a conspicuous position at the ends of the roads. At other times no other than a duly authorized person shall be permitted to travel on foot along the road.

On this system either insulated returns or uninsulated metallic returns of low resistance may be employed.

44. In order to prevent any other part of the system being earthed (except when the concentric system with earthed outer conductor is used) the current supplied for use on the trolley wires with an uninsulated return shall be generated by a separate machine, and shall not be taken from or be in connexion with electric lines otherwise completely insulated from earth.

45. If storage battery locomotives are used in any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, the rules applying to motors in such places shall also be deemed to apply to the boxes containing the cells.

SECTION VII

ELECTRIC LIGHTING

46. All arc lamps shall be so guarded as to prevent pieces of ignited carbon falling from them, and shall not be used in situations where there is likely to be danger from the presence of coal dust. They should be so screened as to prevent risk of contact with persons.

47. Small wires for lighting circuits must be either

conveyed in pipes or casings, or suspended from porcelain insulators, or tied to them with some non-conducting material which will not cut the covering, and so that they do not touch any timbering or metal work. On no account must staples be used. If metallic pipes are used they must be electrically continuous earthed. If separate uncased wires are used they must be kept at least 2 in. apart, and not brought together except at lamps or switches or fittings.

48. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, electrical lamps if used must be of the vacuum or enclosed type; they shall be protected by gas-tight fittings of strong glass, and have no flexible cord connexions, and shall only be changed by a duly authorized competent person. While the lamps are being changed the current shall be switched off.

49. In all machine rooms and other places underground, where a failure of electric light is likely to cause danger, some safety lamps or other proper lights shall be kept for use in the event of such failure.

SECTION VIII

SHOT-FIRING

50. Electricity from lighting or power cables shall not be used for firing shots, except in sinking shafts or stone drifts, and then only when a special firing plug, button, or switch is provided, which plug, button, or switch shall be placed in a fixed locked box, and shall only be accessible to the authorized shot-firer.

The firing cables or wires shall not be connected to this box until immediately before it is required for the firing of shots, and shall be disconnected immediately after the shots are fired.

When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables.

The foregoing rules shall not apply to telephone, telegraph, and signal wires, to which the rules of this section only shall apply.

SECTION IX

SIGNALLING

51. All proper precautions must be taken to prevent electric signal and telephone wires from coming into contact with other electric conductors, whether insulated or not.

52. Contact makers or push buttons of electric signalling circuits shall be so constructed and placed as to prevent the circuit being accidentally closed.

53. In any place or part of a mine where General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, bare wires shall not be used for signalling circuits except in haulage roads, and the pressure shall not exceed 15 volts in any one circuit.

SECTION X

ELECTRIC RELIGHTING OF SAFETY LAMPS

54. In mines to any place or part of which General Rule No. 8 of the Coal Mines Regulation Act, 1887, applies, when safety lamps are relighted underground by electricity, the manager shall select a suitable station or stations, which are not in the return airway, and in which there is not likely to be any accumulation of inflammable gas; and no electric relighting apparatus shall be used in any other place. All electrical relighting apparatus shall be securely locked, so as not to be available for use except by persons authorized by the manager to relight safety

lamps, and such persons shall examine all safety lamps brought for relighting before they are re-issued.

SECTION XI

EXEMPTIONS AND MISCELLANEOUS

55. Notwithstanding anything contained in these rules, any electrical plant or apparatus installed or in use before the coming into force of these rules may be continued in use unless an inspector shall otherwise direct, or subject to any conditions affecting safety that he may prescribe.

In case any difference of opinion shall arise between an inspector and an owner under this Rule, the same shall be settled as provided in Section 42 of the Coal Mines Regulation Act, 1887.

56. Any of the foregoing requirements shall not apply in any case in which exemption is obtained from the Secretary of State, on the ground either of emergency or special circumstances, on such conditions as the Secretary of State may prescribe.

INDEX

A

Adhesion of Locomotives, 106
Alternators, 16
— output of, 20
— parallel running, 29
— power to drive, 24
Aluminium conductors, 44
Ampere meters, 26
Apparent watts, 9
Armouring of cables, 68

B

Battery load equalizers, 152
Boiler-house plant, 13
Boving turbine pump, 109
Brakes, emergency, 161
— rheostatic, 105
— regenerative, 150
— for winding engine, 145

C

Cables, aluminium, 44
Cable boxes, 72–75
— cleats, 66
— drums, 122
— shaft, 62
— suspenders, 66, 71
— trailing, 76
— underground, 62
Capacity of wires and cables, 52–61
Choking coils, 49
Circuit breakers, 26
Coal-cutting, 123
Coal-cutters, types of, 124
Coal-cutter motors, 124
Conductors, aerial, 44
— bare, 42
— determination of size, 42
— and insulation, 63
— method of laying, 69
Controllers for haulages, 92
— liquid, 92, 161
— oil immersed, 91
Current density, 40

D

Depth indicators, 141
Dip pumps, 122
Drilling, 126
Drums for winding engines, 142

E

Earthing, 19
Earth plates, 47
— wires, 84
Electric generators, continuous current, 15
— — alternating current, 18
— lighting, 85
Engines, 13
Equalizing switches, 27

F

Fans, electrically driven, 129
— power required to drive, 130
— regulation of, 131
Flexible couplings, 119
— cable suspenders, 71
Fly-wheel converter, 148
— equalizer, 146

Frequency, 19
Friction in pipes, 118
Fuses, 32

G

Gas engines, 12
Gate end boxes, 77
Generating plant, 11
Generators, electric, continuous current, 15
— with inter-poles, 16
— alternating current, 18
— — speed of, 19
— power required to drive, 21

H

Haulage, electric, 87
— main, 96
— main and tail, 97, 98
— endless rope, 99
— controllers, 92
— motors, 91
— — rating, 90
— resistances, 92
Home Office Regulations, 163
— cables, 169
— definitions, 163
— exemptions, 178
— general, 164
— generating stations, 168
— lighting, 175
— locomotives, 174
— miscellaneous, 178
— motors, 172
— safety lamps, 177
— shot firing, 176
— signalling, 177
— switches, fuses, etc., 172
Horse-Power for coal cutters, 126
— for generators, 21
— for haulages, 96–102
— for pumps, 117
— for ventilating fans, 113
— for winding, 135–140

I

Impedance, 8
Induction motors, 112
Instrument transformers, 30
Interpoles, 16
Isolating switches, 32

K

Kelvin's law, 41
Keope pulley, 143
Kilo volt amperes (K.V.A.), 22
Kinetic energy, 146

L

Lagging currents, 7
Leakage indicators, 35
Lightning arresters, 47
Lighting, electric, 85
— transforms, 85
Lock-coil armouring, 68
Locomotives, electric, 102
— equipment, 105

M

Motors, alternating current, 14
— — speed of, 116
— — starting performance, 113
Motor generators, 14
Motors for haulage, 90–91
— for fans, 131

N

Nalder Bros.' leakage indicator, 35

O

Ohm's law, 3–8
Oil-immersed controllers, 91
Oil switches, 28

P

Parallel drums, 142

Pipe friction, 118
Poles, 45
Power factor, 9, 10
Pressure drop, 3, 8, 21
Pumps, Cornish, 107
— dip, 122
— motors for, 111, 113
— plunger, 108
— power required, 117
— priming, 130
— speed of, 110
— sinking, 119
— turbine, 109

R

Ram pumps, 108
Reel drums, 144
Regenerative braking, 180
Regulation of motors, 131–133
Relays, 33
Resistance, 3
— of conductors, 51–61
Reversible booster, 154
Rheostats, 26, 30
Rope speeds, 145

S

Short circuiting devices, 113
Short circuited rotors, 113
Siemen's Ilgner system, 147
Sinking pumps, 119
— — control, 126
Slip of induction motors, 116
Speed of induction motors, 116
— — — control, 131
Spiro-conical drums, 143
Starting resistances, 113
— transformers, 113
Star-mesh starters, 114
Stranded cables, 52–61
Switches, equalizing, 27
— isolating, 32
— oil, 28
Switch-gear for continuous current, 25
— for alternating current, 28
— for haulage motors, 92
Suspension of conductors, 44
Synchronizers, 29

T

Terminal poles, 48
Time limit relays, 33
Trailing cables, 126
Transformers for lighting, 85
— for instruments, 28–30
Transmission, 39
— poles, 48
Trip coils, 29
Trolley for locomotive, 105
Turbines, 13
Turbine pump, 109

V

Valves, non-return, 120
Ventilating, electric, 129
— fans, 130
Voltage drop, 21
— continuous, 3
— alternating, 5
Volt meter, 26
— paralleling, 27

W

Watts, apparent, 9
— true, 3, 9
Watt meters, 34
Weight of conductors, 52–61
Winding, electric, 134
— — acceleration, 139
— — efficiency, 140
— load curve, 138, 151
— speed of, 137
— system, Crompton's, 152
— — Siemen's Ilgner, 147
— — Westinghouse, 157

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